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COUNCIL ON COMPETITIVENESS

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GAINING NEW GROUND:

TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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FOREWORD

This report examines the erosion of America's once-commanding lead in critical technologies — and more important, recommends what the nation must do to get it back.

In it, we ask one basic question: Do our current national policies and priorities adequately address the commercial technology challenge facing the United States? We conclude they do not. Although the U.S. government and private sector have made some strides in recent years, our competitors are moving faster.

We must do more. First and foremost, the nation must define its goals to include a priority focus on technology that supports economic growth. The whole world has marveled at the technological superiority demonstrated by the U.S. military in the Persian Gulf. The challenge is to make equally good use of technology to help fight the recession at home and improve America's competitiveness in international markets.

Pioneering research and Nobel prizes are not enough. Leadership in technology is closely linked to leadership in commercial markets. Unless ideas can be pushed, pulled and cajoled from the laboratory to the marketplace and unless technological know-how meets the test of markets, America's jobs, standard of living and, ultimately, national security will be at risk. Our national technology priorities must address this marketplace reality.

Instead of focusing on sector-specific recommendations and special-interest politics, we need to develop a national consensus that supports the core technologies that cut across many different sectors of the economy and drive U.S. industrial productivity and economic growth. In this report, the Council identifies such technologies.

This project was characterized by uncommon cooperation and involvement on the part of the public and private sectors. In preparing the report, the Council worked closely with top R&D experts across the country and consulted extensively with government officials. We conducted an in-depth analysis of nine major technology-intensive industries: 1) aerospace, 2) chemicals and allied products, 3) computers and software, 4) construction, 5) drugs and pharmaceuticals, 6) electronic components and equipment, 7) machine tools, 8) motor vehicles and 9) telecommunications. These sectors represent a broad cross section of the American economy. Together, they account for more than $1 trillion of sales and directly employ about 12 million people. In many respects, our current and future prosperity depends on the performance of these industries. In assessing the specific technology requirements of each sector, the Council asked three primary questions: Where is the common ground? What are the common denominators? Beyond the parochial interest of each sector, what is the ***national*** interest?

Although this report represents the first time that America's corporate, academic and labor leaders have reached consensus on these questions, the Council has not been alone in attempting to identify the generic technologies that benefit many sectors. Various industry groups and agencies in the U.S. government, Japan and Europe have all published critical technology lists.

These lists are striking in their similarity. Despite their different goals and national perspectives, experts from Brussels to Tokyo to Washington essentially agree that future economic prosperity depends on leadership in the same basic technologies.

This remarkable consensus underscores a crucial point in the technology debate: we need to move beyond simply making lists. Instead, America needs a pragmatic plan for public- and private-sector action.

This report provides such an action plan. It spells out five major recommendations, two for the public sector and three for the private sector. Within each recommendation, the report highlights several specific proposals for improving U.S. technological competitiveness. The Council's Executive Committee has reached consensus on this action plan, although individual members may not necessarily agree with all the specifics of each recommendation.

The prerequisite for action is leadership — starting with the President and extending throughout the Executive Branch and Congress, and starting with chief executives and extending throughout corporations, universities and labor unions across the country. Each sector has a unique responsibility — government to foster an environment that supports the development, use and commercialization of technology; universities to help discover new knowledge and to educate inventors, engineers and managers; and industry to take ideas from laboratories to the marketplace.

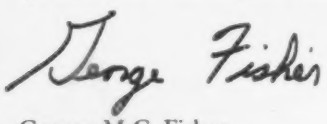
For its part, the Council on Competitiveness intends to expand its leadership role. In 1988, with the publication of *Picking Up the Pace*, the Council helped to build greater understanding of the importance of technology commercialization and to refocus U.S. science and technology policy. With *Gaining New Ground*, the Council not only spells out an action plan, but also commits itself to mounting an intensive effort to implement the report's recommendations.

We recognize that technology alone will not make America competitive in world markets. The United States also must reform its education and training system, improve its macroeconomic policies and push for continued openness of foreign markets. But progress in these other areas must be matched by a strong technology base.

Unless the United States shores up its technological strength, Americans will feel the pinch in a thousand ways. The good jobs they seek will always be out of reach. The mortgage payments they make will take a bigger bite out of their paychecks. The national security that they have become accustomed to will become more precarious. And the high standard of living that Americans once took for granted will be beyond the grasp of future generations.

The stakes are high. Technology not only saves lives, but improves the quality of life. It is what makes machinery more reliable, information more accessible and transportation more convenient. Most important, by improving the quality of goods and services and the productivity of the work force, technology is the driving force behind America's competitiveness.

We must do better. Working together to carry out the kinds of reforms advocated by this report, we will.



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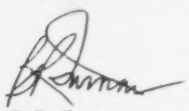

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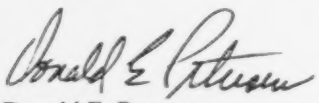

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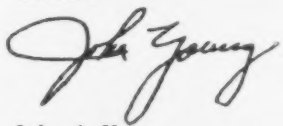

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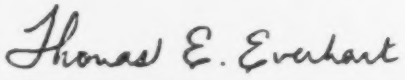

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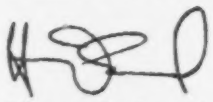


Howard D. Samuel
Council Vice Chairman

Executive Summary

Throughout America's history, technology has been a major driver of economic growth. It has carried the nation to victory in two world wars, created millions of jobs, spawned entire new industries and opened the prospect of a brighter future. In many respects, technology has been America's ultimate comparative advantage. Because of our great technological strength, U.S. manufacturing and service industries stood head and shoulders above other nations in world markets.

That comforting view is under assault. As a result of intense international competition, America's technology edge has eroded in one industry after another. The U.S.-owned consumer electronics and factory automation industries have been practically eliminated by foreign competition; the U.S. share of the world machine tool market has slipped from about 50 percent to 10 percent; and the U.S. merchant semiconductor industry has shifted from dominance to a distant second in world markets. Even such American success stories as chemicals, computers and aerospace have foreign competitors close on their heels.

Blame for the problems has been laid at many doorsteps: sluggish domestic productivity growth, closed foreign markets, the deteriorating U.S. education and training system, poor management and misguided government policies in areas ranging from capital formation to product liability laws. Some fear the United States is too preoccupied with national prestige technology projects to worry about investing in the generic enabling technologies that are critical to the competitiveness of many industries. Others charge that the United States is increasingly turning over the difficult job of commercialization and manufacturing technology to foreign companies. Unfortunately, in turning over technology to its competitors, America is turning over the keys to economic growth and prosperity.

The American people and its leaders have too readily assumed that preeminence in science automatically confers technological leadership and commercial success as well. It does not. America assumed that government support for science would be adequate to provide for technology. It is not. In too many sectors, America took technology for granted. Today, the nation is paying the price for that complacency.

This report examines the U.S. position in critical technologies and the actions the nation must take to strengthen it.

Key Findings

1.

THERE IS A BROAD DOMESTIC AND INTERNATIONAL CONSENSUS ABOUT THE CRITICAL GENERIC TECHNOLOGIES DRIVING ECONOMIC GROWTH AND COMPETITIVENESS.

The U.S. Department of Commerce, the U.S. Department of Defense, Japan's Ministry of International Trade and Industry, the European Community and many individual industry groups have all compiled similar lists of critical technologies. This project examined critical technologies from the point of view of a cross section of U.S. industry and confirmed the overlap of critical technologies that appears in these other studies. Given the broad consensus about critical technologies, it is time to move beyond making lists and begin implementing programs that will strengthen U.S. technological leadership.

2.

THE U.S. POSITION IN MANY CRITICAL TECHNOLOGIES IS SLIPPING AND, IN SOME CASES, HAS BEEN LOST ALTOGETHER. FUTURE TRENDS ARE NOT ENCOURAGING.

America pioneered such technologies as numerically controlled machine tools, robotics, optoelectronics and integrated circuits only to lose leadership in them to foreign competitors. Moreover, in many critical technologies, ranging from leading-edge scientific equipment to precision bearings, trends are running against U.S. industry. (See lists on pages 7 to 11.) The erosion of the U.S. position in critical technologies has helped to highlight an important lesson about industrial competition in the late 20th century: a lead in science is not sufficient to sustain technological leadership. Scientific excellence also must be supplemented by a strong position in critical technologies and by the ability to convert these technologies into manufactured products, processes and services that can compete successfully in the marketplace. Otherwise, America's jobs, standard of living and national security will be in jeopardy and, because technology is increasingly driving new scientific advances, so will America's future lead in science.

3.

FOREIGN GOVERNMENTS ARE SYSTEMATICALLY PURSUING LEADERSHIP IN CRITICAL TECHNOLOGIES.

Governments in other major industrialized countries have used R&D incentives, public-private technology consortia, infrastructure programs, tax policy, trade policy and regulations to improve the technological competitiveness of their industries. The most successful efforts combine funding with extensive public-private collaboration. Partly as a result of these programs, U.S. industry has lost extensive market share in many technology-intensive products (such as memory chips and machine tools) and, in some cases, entire industries (such as consumer electronics). Problems arising from foreign government actions have been compounded by the lack of a timely, coordinated and effective U.S. industry and government response.

4.

U.S. PUBLIC POLICY DOES NOT ADEQUATELY SUPPORT AMERICAN LEADERSHIP IN CRITICAL TECHNOLOGIES, AND U.S. NATIONAL PRIORITIES DO NOT SUFFICIENTLY ADDRESS ISSUES RELATED TO THE ROLE OF TECHNOLOGY IN U.S. COMPETITIVENESS.

Other nations already spend more on non-defense R&D as a percent of GDP than the United States, and they are steadily increasing these levels. The United States needs to increase support for R&D and focus more resources on non-defense R&D that is commercially relevant. In 1990, only a relatively small fraction of the $67 billion federal R&D budget was directly relevant to the real technology needs of American industry. The low priority given to technology and competitiveness in the federal R&D budget is reflected in America's tax, trade and regulatory policies. It is also reflected in the decline of public investment in infrastructure, which fell from 5.8 percent of GNP in the mid-1950s to 3.9 percent in the mid-1980s. Unless R&D programs are reinforced by policies in these other areas that encourage private-sector investment in technology, they will have a limited impact on U.S. competitiveness. The most effective programs are those that encourage sharing of the costs and results of precompetitive research and that stimulate private-sector proprietary R&D and commercialization.

5.

MOST OF THE TECHNOLOGIES THAT WILL DRIVE ECONOMIC GROWTH OVER THE NEXT DECADE ALREADY EXIST, AND INDUSTRY NEEDS TO IMPROVE ITS ABILITY TO CONVERT THEM INTO MARKETABLE PRODUCTS AND SERVICES.

Many of the competitiveness problems facing U.S. industry stem from industry's failure to commercialize technology effectively. Although it is important to discover breakthrough technologies that create entire new industries, it is equally important to develop existing technologies that improve industry's performance in large, established markets. In addition to research, market success depends on management systems that encourage the development and application of technology, education and training programs that build work force skills, and world-class commercialization systems. Unless companies have strengths in these areas, they will not be able to translate their technical advantages into technological leadership.

6.

AMERICA'S RESEARCH UNIVERSITIES CONSTITUTE A GREAT NATIONAL ASSET, BUT THEIR FOCUS ON TECHNOLOGY AND COMPETITIVENESS IS LIMITED.

U.S. universities produce first-rate scientists and engineers and conduct pioneering research that lays the foundation for many advances in technology. However, their focus on undergraduate education and on preparing future scientists and engineers for the needs of industry, especially in the manufacturing sector, has been inadequate. A closer relationship with industry would help university faculty broaden their understanding of industry's education requirements, develop appropriate curriculums and motivate students. It would also help university researchers focus on challenging leading-edge technology and manufacturing research that is relevant to the private sector. In reaching out to industry, however, universities should be careful not to jeopardize their basic research programs, which have served the nation well.

Key Recommendations

The recommendations highlighted below stem from one overriding conclusion: **IN ORDER TO CREATE QUALITY JOBS, GENERATE STRONG ECONOMIC GROWTH AND SAFEGUARD NATIONAL SECURITY, THE U.S. GOVERNMENT AND PRIVATE SECTOR SHOULD WORK TOGETHER TO DEVELOP COHERENT POLICIES TO ENSURE U.S. LEADERSHIP IN THE DEVELOPMENT, USE AND COMMERCIALIZATION OF TECHNOLOGY.**

The first two recommendations focus on actions that the federal government should undertake; the second two on U.S. industry's responsibilities; and the last on what American universities can do. Taken together, they would make a major contribution to America's technological competitiveness. An in-depth discussion of these recommendations can be found in Chapter IV (pages 44-54).

1.

TO ENHANCE U.S. COMPETITIVENESS, THE PRESIDENT SHOULD ACT IMMEDIATELY TO MAKE TECHNOLOGICAL LEADERSHIP A NATIONAL PRIORITY.

The United States is already losing badly in many critical technologies. Unless the nation acts today to promote the development of generic industrial technology, its technological position will erode further, with disastrous consequences

for American jobs, economic growth and national security. The federal government should view support of generic industrial technologies as a priority mission. It is important to note that this mission would not require major new federal funding. If additional funds for generic technology programs are required, other federal R&D programs, such as national prestige projects, should be redirected or phased in more slowly to allow more resources to be focused on generic technology. The President should move quickly to take the following actions:

- Announce his intention to increase dramatically the percentage of federal R&D expenditures allocated to support for critical generic technologies and present a five-year implementation plan as part of his FY1993 budget.
- Direct the Office of Science and Technology Policy and the newly created Critical Technologies Institute to work with industry to set priorities in critical generic technologies, translate these priorities into specific action plans and implement these programs.
- Direct key technology agencies — such as the National Science Foundation, the National Institutes of Health, the National Institute of Standards and Technology, and the Defense Advanced Research Projects Agency — to work with industry to advance U.S. leadership in critical generic technologies.
- Implement decisions to ensure that the federal laboratories' contribution to U.S. technological leadership and competitiveness is commensurate with the national investment in them.
- Make the cost of capital for the development of priority technologies competitive with that of America's major competitors by accelerating depreciation schedules for manufacturing equipment, making the R&D tax credit permanent and broadening it to include manufacturing engineering and process R&D, and placing a permanent moratorium on Treasury Regulation 1.861-8.
- Promote capital formation, antitrust reforms, regulatory guidelines, export policies and foreign market-opening measures that are conducive to U.S. manufacturing, investment in technology and quality of life.
- Make technological leadership a central theme in the Administration's public communications efforts and highlight it in the President's annual State of the Union address, budget submissions and other messages on national priorities.
- Ensure that key policymaking bodies, such as the National Security Council and relevant agencies and departments, are more closely involved in issues related to technology and competitiveness.

2.

THE FEDERAL AND STATE GOVERNMENTS SHOULD DEVELOP POLICIES AND IMPLEMENT PROGRAMS TO ENSURE THAT AMERICA HAS A WORLD-CLASS TECHNOLOGY INFRASTRUCTURE.

The nation's technology infrastructure is critical to its international competitiveness, national defense and world leadership. Technology infrastructure consists of physical assets, such as equipment, facilities and networks, and human capital, such as skilled scientists, engineers and other personnel. Infrastructure programs traditionally have been a responsibility of the federal and state governments. The federal government should assess the nation's technology infrastructure needs, benchmark what foreign governments are doing and develop strategies, programs and implementation plans to make sure that the United States has a world-class technology infrastructure. The Administration's 1989 report on high performance computing and networking, as well as related Congressional legislation, represent an infrastructure program that should be fully implemented. The following are essential aspects of a successful technology infrastructure program:

■ Broad relevance to many sectors of the U.S. economy.

■ Close links with public- and private-sector efforts to develop relevant critical generic technologies.

■ Support for education at all levels.

■ Investment in related university research, education, facilities and equipment.

■ Measures that make it easy for industry to invest in, deploy and use infrastructure to enhance its competitiveness.

3.

U.S. INDUSTRY SHOULD ESTABLISH MORE EFFECTIVE TECHNOLOGY NETWORKS TO HELP IT COMPETE IN THE INTERNATIONAL MARKETPLACE.

U.S. industry associations, professional societies, R&D consortia, universities and research institutes should all play more substantial roles promoting technological collaboration and in diffusing technology and information that promote America's technological competitiveness. Although there is an understandable sensitivity to sharing proprietary technology, the United States can, and must, do a better job of diffusing new ideas throughout industry and of sharing the cost and risk of developing technology. The Council on Competitiveness will take a leading responsibility to work with these organizations to promote technology networks. Industry groups and associations should take the following actions:

■ Strengthen their competence in technology issues.

■ Promote antitrust reforms that enable them to establish technology networks and share information about international market developments.

■ Identify and disseminate information about key generic technologies and world-class commercialization practices throughout the U.S. private sector.

■ Jointly assess critical generic technologies and develop technology road maps to boost U.S. competitiveness.

■ Build cooperative supplier networks that help set standards and share information in critical technologies.

4.

U.S. FIRMS SHOULD SET A GOAL TO MEET AND SURPASS THE BEST COMMERCIALIZATION PRACTICES OF THEIR COMPETITORS.

American management needs to improve its ability to commercialize technology. U.S. companies should understand and build on the successful commercialization practices of their domestic and foreign competitors. To achieve this goal, U.S. firms should benchmark their competitors. They should set appropriate goals and allocate the necessary resources. They should motivate, train and empower their employees to take responsibility for achieving these goals. And they should develop the external relationships necessary to accelerate the commercialization process. The Council on Competitiveness will play a role in encouraging industry to take these steps. Action in the following areas is especially important:

■ Match the Administration's goal to increase dramatically the R&D allocated to critical generic technologies and develop a five-year implementation plan (see recommendation 1).

■ Institute total quality management and continuous improvement.

■ Strengthen process engineering.

■ Accelerate time-to-market to competitive levels.

■ Improve the ability to share risks and spread costs for developing technology across a broad base.

■ Continuously upgrade the skills of the work force.

■ Encourage corporate executives and general managers to give strategic factors equal weight with financial projections in technology-based businesses.

5.

WHILE KEEPING THEIR BASIC RESEARCH PROGRAMS STRONG, UNIVERSITIES SHOULD DEVELOP CLOSER TIES TO INDUSTRY SO THAT EDUCATION AND RESEARCH PROGRAMS CONTRIBUTE MORE EFFECTIVELY TO THE REAL TECHNOLOGY NEEDS OF THE MANUFACTURING AND SERVICE SECTORS.

America's research universities are one of its great technological assets and should be strengthened. In pursuit of new knowledge, however, many universities have lost sight of issues related to technology and manufacturing that affect U.S. competitiveness. Universities should strengthen their focus on the manufacture, use and commercialization of technology. In the process, however, it is important not to jeopardize the basic research contributions of universities. Universities should focus on the following actions:

■ Develop close ties with U.S. industry and make efforts to ensure that important technological advances are communicated to potential U.S. users on a priority, expedited basis.

■ Make efforts, in cooperation with employers, to ensure that education programs in engineering and management reflect the real needs of industry.

■ Keep basic science and engineering programs strong and strengthen research capabilities so that they can adequately address fundamental, long-term technology issues that are relevant to industry.

Critical Technologies

The following list of critical generic technologies represents the private sector's assessment of the technologies that will drive U.S. productivity, economic growth and competitiveness during the decade ahead. These technologies span different sectors of the U.S. economy. They are divided into five categories: 1) materials and associated processing technologies, 2) engineering and production technologies, 3) electronic components, 4) information technologies and 5) powertrain and propulsion technologies.

The list also includes an assessment of the U.S. competitive position in each technology. The assessment is based on extensive analysis and reflects the judgment of experts in industry who understand both the critical technologies and the relevant markets. In general, the competitive position shows the status of technologies that are incorporated in products or processes ***in the marketplace***, rather than technologies ***in the laboratory***. The U.S. position in each of the technologies is categorized in one of four ways:

■ **Strong** — U.S. industry is in a leading world position and is not in danger of losing this position in the next five years.

■ **Competitive** — U.S. industry is roughly even with world-best. This category includes technologies where the United States is leading but the leadership is unlikely to be sustained over the next five years, technologies where the United States is staying even and technologies where different countries lead in different niches.

■ **Weak** — U.S. industry is behind in technology or likely to fall behind in the next five years. Changes are needed if the United States is to remain in the businesses related to this technology.

■ **Losing Badly or Lost** — U.S. industry is no longer a factor or is not likely to have a presence in the next five years. It will take considerable effort or a major change in technology for the United States to become competitive.

MATERIALS AND ASSOCIATED PROCESSING TECHNOLOGIES

TECHNOLOGY	U.S. POSITION			
	Strong	Competitive	Weak	Losing Badly or Lost
Advanced Structural Materials				
Advanced Metals			■	
Metal Matrix Composites		■		
Polymers		■		
Polymer Matrix Composites		■		
Structural Ceramics				■
Electronic and Photonic Materials				
Display Materials				■
Electronic Ceramics				■
Electronic Packaging Materials				■
Gallium Arsenide				■
Magnetic Materials		■		
Optical Materials		■		
Photoresists		■		
Silicon				■
Superconductors		■		
Biotechnologies				
Bioactive/Biocompatible Materials	■			
Bioprocessing	■			
Drug Discovery Techniques	■			
Genetic Engineering	■			
Materials Processing				
Catalysts		■		
Chemical Synthesis		■		
Membranes			■	
Net Shape Forming		■		
Precision Coating			■	
Process Controls		■		
Environmental Technologies				
Emissions Reduction	■			
Recycling/Waste Processing	■			

Source: Council on Competitiveness

ENGINEERING AND PRODUCTION TECHNOLOGIES

TECHNOLOGY	U.S. POSITION			
	Strong	Competitive	Weak	Losing Badly or Lost
Design and Engineering Tools				
Computer-Aided Engineering	■			
Human Factors Engineering		■		
Leading-Edge Scientific Instruments			■	
Measurement Techniques		■		
Structural Dynamics		■		
Systems Engineering	■			
Commercialization and Production Systems				
Computer-integrated Manufacturing		■		
Design for Manufacturing			■	
Design of Manufacturing Processes			■	
Flexible Manufacturing			■	
Integration of Research, Design and Manufacturing			■	
Total Quality Management			■	
Process Equipment				
Advanced Welding		■		
High-Speed Machining			■	
Integrated Circuit Fabrication and Test Equipment				■
Joining and Fastening Technologies		■		
Precision Bearings			■	
Precision Machining and Forming			■	
Robotics and Automated Equipment				■

Source: Council on Competitiveness

ELECTRONIC COMPONENTS

TECHNOLOGY	U.S. POSITION			
	Strong	Competitive	Weak	Losing Badly or Lost
Microelectronics				
Logic Chips		■		
Memory Chips				■
Microprocessors	■			
Submicron Technology		■		
Electronic Controls				
Actuators			■	
Sensors		■		
Optoelectronic Components				
Laser Devices			■	
Photonics			■	
Electronic Packaging and Interconnections				
Multichip Packaging Systems				■
Printed Circuit Board Technology				■
Displays				
Electroluminescent				■
Liquid Crystal				■
Plasma and Vacuum Fluorescent				■
Hardcopy Technology				
Electro Photography			■	
Electrostatic			■	
Information Storage				
Magnetic Information Storage	■			
Optical Information Storage				■

Source: Council on Competitiveness

INFORMATION TECHNOLOGIES

TECHNOLOGY	U.S. POSITION			
	Strong	Competitive	Weak	Losing Badly or Lost
Software				
Applications Software	■			
Artificial Intelligence	■			
Computer Modeling and Simulation	■			
Expert Systems	■			
High-Level Software Languages	■			
Software Engineering	■			
Computers				
Hardware Integration		■		
Neural Networks	■			
Operating Systems	■			
Processor Architecture	■			
Human Interface and Visualization Technologies				
Animation and Full Motion Video	■			
Graphics Hardware and Software	■			
Handwriting and Speech Recognition	■			
Natural Language	■			
Optical Character Recognition	■			
Database Systems				
Data Representation	■			
Retrieval and Update	■			
Semantic Modeling and Interpretation	■			
Networks and Communications				
Broadband Switching		■		
Digital Infrastructure		■		
Fiber Optic Systems		■		
Multiplexing		■		
Portable Telecommunications Equipment and Systems				
Digital Signal Processing		■		
Spectrum Technologies		■		
Transmitters and Receivers	■			

Source: Council on Competitiveness

POWERTRAIN AND PROPULSION TECHNOLOGIES

TECHNOLOGY	U.S. POSITION			
	Strong	Competitive	Weak	Losing Badly or Lost
Powertrain				
Alternative Fuel Engines		■		
Electric Motors and Drives		■		
Electrical Storage Technologies		■		
High Fuel Economy/ Power Density Engines			■	
Low Emission Engines	■			
Propulsion				
Airbreathing Propulsion	■			
Rocket Propulsion	■			

Source: Council on Competitiveness

KEY LESSONS

Several lessons can be drawn from examining the U.S. position in these technologies. Some of the most important are summarized below.

■ The strong across-the-board U.S. position of a decade ago has deteriorated significantly. U.S. industry has already lost several technologies that are critical to industrial performance, and it is weak or losing badly in others. Moreover, trends are running against the United States — in most technologies, the U.S. position continues to erode.

■ Technologies where the United States is "strong" or "competitive" share many of the following characteristics:

– They are close to basic research or are the direct result of basic research without the intervening steps of lengthy technology development (biotechnology).

– They do not have heavy capital investment needs (software).

– They can be initiated largely by individual innovation (computer-aided engineering).

– They are strongly supported by U.S. government investment in basic research (genetic engineering), defense procurement (rocket propulsion) and environmental regulations (emissions reduction).

– They have been supported by high levels of private-sector R&D (materials and information technologies).

■ Many of the areas where the United States is "weak" or "losing badly" have the following characteristics:

– They have not had sufficient private or public investment in the underlying technology (display materials).

– There is inadequate risk-sharing among companies in technology development (electronic packaging).

– They have high capital needs and low capital investment (automated equipment).

– They need extensive investment in technology for an extended period of time (optical information storage).

– They have a significant manufacturing focus (integrated circuit fabrication equipment).

– They have been targeted by foreign government and industry (memory chips).

CHAPTER I

TECHNOLOGY POLICY AND GLOBAL COMPETITION

The United States traditionally has been a formidable competitor in world technology markets. American industries such as computers, pharmaceuticals, aircraft and medical instruments are the envy of the world. In recent years, however, many U.S. technology-intensive industries have stumbled in the face of foreign competition. In some cases, the setbacks have been temporary — the American chemical industry restructured during the 1970s to emerge as a world leader in the 1980s.

In too many cases, however, the consequences have been disastrous: the U.S. share of the world machine tool market has slipped from about 50 percent to 10 percent; the American-owned consumer electronics industry has been virtually eliminated by foreign competition; and the U.S. merchant semiconductor industry has shifted from dominance to a distant second in world markets.

Initially, each of these problems was viewed as an isolated development. As they mounted, however, they raised serious questions about the strength of U.S. technology-intensive industries and the implications for America's economic well-being and national security. Will computers follow semiconductors as the next victim of international competition? Will the U.S. aerospace industry ultimately go the same way as machine tools? Will the U.S. auto industry reemerge as a world-class leader?

These questions have sparked a national debate about technology and competitiveness. At one time or another, America's technology problems have been blamed on external economic shocks, closed foreign markets, misguided macroeconomic policies, poor management and a host of other issues. Underlying these explanations, however, is a growing realization that the rules of the game have changed. High technology was once viewed as the inviolate advantage of American industry. Now it is the inevitable target of foreign competition, with serious consequences for the U.S. economy.

This realization has prompted a reassessment of America's technology priorities. The United States can no longer take technological leadership in commercial markets for granted. Both private industry and the federal government must re-evaluate their approach to the development and application of technology. Industry is on the front lines and bears the ultimate responsibility

for the commercialization process. By itself, however, the private sector will be unable to stem the tide. Public policies will also have to change to accommodate the reality of intense competition in technology.

The erosion of the U.S. technology base has focused attention on one overriding question: What is the best way to promote American leadership in the generic enabling technologies that will drive economic growth and national security during the next decade? These generic technologies cut across different sectors of the economy and boost overall productivity growth and industrial performance. (For a full discussion, see Chapter II.) Unless the nation has a strong position in these areas, American jobs, economic growth and, ultimately, the standard of living and national security will suffer.

U.S. Federal Support for Science and Technology

U.S. government support for science and technology can be divided into two categories: 1) infrastructure and 2) R&D. Technology infrastructure consists of the physical assets and human capital that support economic activity. It includes not only hardware in the form of plant, equipment, laboratories, facilities and networks, but also scientists, engineers and skilled workers. Infrastructure programs traditionally have been a responsibility of the U.S. federal and state governments. Since the 1950s, however, U.S. public investment in infrastructure has been declining as a percent of GNP. From 1950 to 1955, public investment in infrastructure was equal to 5.8 percent of GNP, or 1.9 percent when military spending, schools and highways were excluded. By 1986 to 1987, public investment in infrastructure had declined to 3.9 percent of GNP, or 1.5 percent when military spending, schools and highways were not included.[1] By contrast, many of America's industrial competitors view technology-based infrastructure as essential to their future economic growth and competitiveness, and they are increasing their investment in strategic infrastructure programs.

In addition to infrastructure, the U.S. government has traditionally played an important role in supporting R&D. U.S. government support for R&D has focused on basic research and specific national missions. It assumes that because industry cannot capture all of the benefits that stem from basic research, the private sector naturally will tend to underinvest in it. Because basic research has great long-term potential benefits to society, however, the government must make the necessary investments. As a result, U.S. science and technology policy has tended to focus primarily on support for basic research. When public support has gone beyond research to encourage the development and application of technology, it has done so only in areas that are explicitly defined as broader national priorities, such as defense, health and space exploration.

The United States is unique among leading industrial countries in that it has not singled out industrial competitiveness as one of its national R&D priorities. (For an extended discussion of this issue, see Chapter III.) While other governments devote considerable resources to R&D that supports industrial development, U.S. federal funding of R&D for industrial development is almost nonexistent. In 1988, only 0.2 percent of the U.S. federal R&D budget was devoted to industrial development, compared to 4.8 percent for Japan and 14.5 percent for West Germany. (See Table 1.)

The low priority given to R&D that supports industrial development is reflected in agency funding trends over the past decade. While federal R&D for most technology agencies and missions expanded significantly during the 1980s, funding for federal R&D programs at the Department of Commerce, which focus on U.S. industry's manufacturing technology needs,

Table 1
1988 R&D APPROPRIATIONS BY MISSION
(percent of total federal government R&D budget)

	U.S.	Japan	W. Germany
Industrial Development	**0.2**	**4.8**	**14.5**
Defense	65.6	4.8	12.5
Health	12.8	2.6	3.6
Energy	3.9	22.3	7.8
Advancement of Research	3.8	7.6	13.3
General University Funds	(a)	43.7	30.8
Infrastructure (b)	1.8	1.8	1.8
Agriculture	2.0	3.9	2.1
Civil Space	7.4	6.1	5.4
Environmental Protection	0.5	0.5	3.4
Other (c)	1.8	2.0	4.8

(a) The United States has no equivalent to Europe's and Japan's General University Funds.
(b) Includes transport, telecommunications and rural and urban planning.
(c) Includes social development and services, earth and atmosphere, and R&D that is not elsewhere classified.
Note: Numbers may not add to 100 percent due to rounding.

Source: Organization for Economic Cooperation and Development, National Science Foundation and national sources for Japan.

dropped by about $100 million in real terms. By contrast, in real terms from 1980 to 1990 the R&D budget for the Department of Defense (DOD) increased by $11.4 billion, for the National Institutes of Health (NIH) by $1.1 billion, for the National Aerospace and Aeronautics Administration (NASA) by $1.9 billion and for the National Science Foundation (NSF) by $400 million. (See Table 2.)

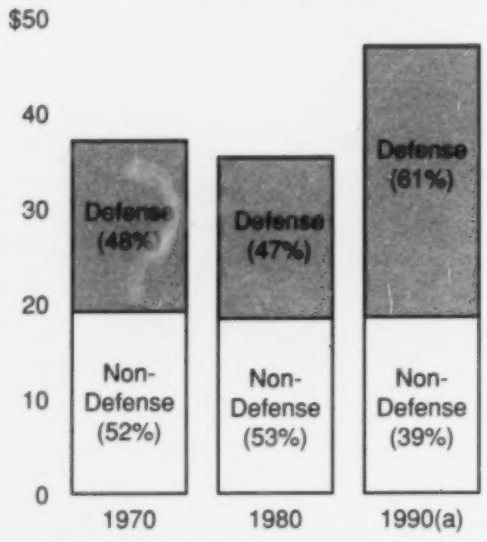
A related issue that deserves attention is the mix of federal funding for defense and nondefense R&D. The imbalance between the two became especially acute in the 1980s as increases in defense R&D dramatically outstripped those for nondefense R&D. (See Figure 1.) From 1980 to 1990, federal funding for defense R&D jumped from 47 percent of the government total R&D spending to 61 percent. It peaked in

Table 2
FEDERAL SPENDING FOR R&D BY AGENCY
(constant 1982 dollars, in billions)

	1980	1985	1990	Net Change
Commerce	$ 0.4	$ 0.4	$ 0.3	($ 0.1)
Defense	$16.5	$26.6	$27.9	$11.4
Energy	$ 5.7	$ 4.5	$ 5.1	($ 0.6)
HHS (NIH)	$ 4.5	$ 4.8	$ 5.6	$ 1.1
NASA	$ 3.8	$ 3.0	$ 5.7	$ 1.9
NSF	$ 1.1	$ 1.2	$ 1.5	$ 0.4

Source: National Science Foundation and *Science and Engineering Indicators — 1989*, National Science Board.

Figure 1
U.S. FEDERAL SPENDING ON DEFENSE AND NONDEFENSE R&D
(constant 1982 dollars, in billions)



(a) Estimate.

Source: National Science Foundation and *Science and Engineering Indicators — 1989*, National Science Board.

percentage terms in 1986, when it accounted for 64 percent of total government R&D spending. The rise in defense R&D was mirrored by a drop in nondefense R&D, which fell from 53 percent of the government total in 1980 to 39 percent in 1989.

Not only did nondefense research decline, but the parts of the defense R&D budget that are most relevant to industry — basic and applied research (line items 6.1 and 6.2 of the DOD budget) — did not share in the big build-up in defense R&D during the 1980s.

It is also important to note that as a percent of total U.S. public and private investment in nondefense R&D, federal spending has fallen significantly during the past two decades. In 1970 the federal government funded 31 percent of total U.S. investment in nondefense R&D; by 1989, federal funding accounted for only 17 percent of the total. The big drop occurred in the years 1980 to 1985. (See Table 3.) During the 1990s, the United States will need to focus increasingly on nondefense R&D, and, within this category, on R&D that is relevant to the real-world needs of American industry. This shift in government R&D priorities must be supported by policies that address issues related to competitiveness and the commercial application of technology.

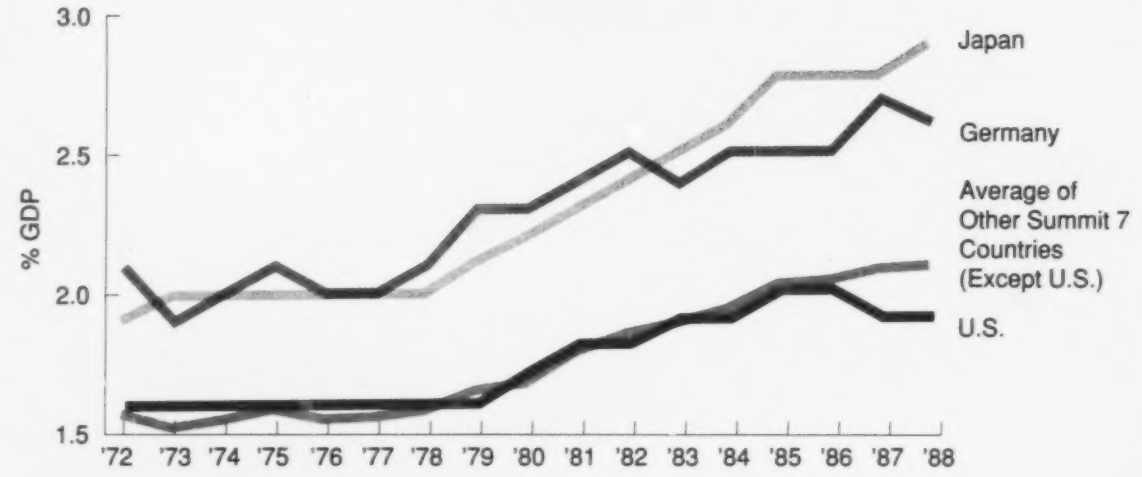
Not only has federal nondefense R&D funding failed to keep pace with commercial or defense R&D, but total (government and private-sector) U.S. nondefense R&D funding also has failed to keep pace with that of other industrialized countries (See Figure 2, page 16). Although the United States leads all nations in terms of absolute dollars spent on R&D investment, Japan and Germany both spend about 50 percent more on nondefense R&D as a percent of GDP than the United States. The U.S. nondefense R&D expenditures are also growing more slowly than its rivals. Since 1972, the United States has slightly increased the percent of GNP it spends on nondefense R&D while the nation's principal economic competitors have increased their expenditures by about 50 percent.

Table 3
U.S. FEDERAL FUNDING FOR NONDEFENSE R&D
as a Percent of the National Total

1970	1975	1980	1985	1990
31%	29%	26%	17%	17%

Source: *Science and Engineering Indicators — 1989*, National Science Board.

Figure 2
INVESTMENT
Nondefense R&D Expenditures



Source: Council on Competitiveness and National Science Foundation.

Evolution of U.S. Technology Policy

There is growing evidence that the federal government recognizes the importance of technology and competitiveness and is beginning to develop policies and programs to address this issue. The basic framework for U.S. government support of science and technology in the postwar era can be traced to the Vannevar Bush report of 1945 entitled, *Science: The Endless Frontier*. This report argued that support for science was an appropriate role for the government and that more applied areas should be left to industry. This policy served the nation well during the two decades following World War II when U.S. industry dominated world markets. Since then, however, the situation has changed. Other countries have concentrated their resources on industrial technology and made deep inroads into markets once dominated by U.S. industries.

During the 1980s, the U.S. federal government began to recognize the competitiveness challenges facing American industry and launched several noteworthy technology initiatives. The 1980 Stevenson-Wydler Technology Innovation Act, which focused on broad support of technological innovation, was one of the early efforts. It was followed by the Bayh-Dole Act and the Patent Term Restoration Act, which attempted to broaden the legal protection for inventors. The National Cooperative Research Act of 1984 relaxed the antitrust laws for research consortia, and in 1985 the charter of the National Science Foundation was amended to give engineering a stronger role. The Technology Transfer Act of 1986 and Executive Order 12591 established a system of cooperative agreements and sought to increase technology transfer between the federal labs and private firms.[2]

An especially significant program was launched in late 1987 when Congress appropriated $100 million for Sematech, a research consortium of firms from the U.S. semiconductor industry that was established to counter intense competition from overseas manufacturers. Federal

funding for Sematech, which is matched by the private sector, was envisioned to continue for five years. Sematech's goal is to develop manufacturing technology for a new generation of integrated circuits. As of 1989, Sematech's R&D program was on track and on time. In addition to R&D, Sematech emphasizes transferring technology to its members, improving supplier relations and strengthening the U.S. technology base through Centers of Excellence at 11 major universities.[3]

Other key federal initiatives include creating the Malcolm Baldrige Quality Award, elevating the National Science Advisor to Assistant to the President for Science and Technology, strengthening the Office of Science and Technology Policy (OSTP) and establishing the Technology Administration at the Department of Commerce. In addition, the federal government has released several reports on critical technologies. The Department of Commerce has released two surveys of emerging technologies.[4] The Department of Defense and the OSTP also have prepared reports on critical technologies and are required by legislation to update them on a regular basis.[5] The OSTP has also released a report, *The Federal High Performance Computing Program*, which represents an action plan for the development of critical technology and related infrastructure in computing. This initiative was followed up with Congressional legislation.

Despite the lengthening list of new federal initiatives, however, much of the U.S. private sector is concerned that much more remains to be done. Some new policies, such as the Stevenson-Wydler Act and Technology Transfer Act of 1986, have been only partially implemented. Funding for new programs is limited and the tax code does not provide adequate incentives for investment in R&D. Moreover, new programs have not been backed by clear priorities or a strategy to promote U.S. technological competitiveness.

Importance of Generic Technologies

For the private sector, a major concern is the need to create a strong climate for investment in, and commercialization of, technology. A key ingredient is federal support for precompetitive R&D on generic technologies that cut across different sectors of the economy and drive industrial performance. The OSTP defines these terms as follows:

- **Generic Technology** — A concept, component, or process, or the further investigation of scientific phenomena, that has the potential to be applied to a broad range of products or processes. Note: A generic technology may require subsequent research and development for commercial application.
- **Precompetitive R&D**— Research and development activities up to the stage where technical uncertainties are sufficiently reduced to permit preliminary assessment of commercial potential and prior to development of application-specific commercial prototypes. Note: At the stage of precompetitive research and development, for example, results can be shared within a consortium that can include potential competitors without reducing the incentives for individual firms to develop and market commercial products and processes based upon the results.

It is important to recognize that generic technology is often synonymous with process technology because it cuts across different sectors and can be widely applied by different firms and even different industries. It is also important to understand that what constitutes generic technology may vary from industry to industry. For example, in science-based industries a basic research breakthrough has the potential to be transformed quickly into a commercial product. Therefore, in industries such as pharmaceuticals, generic technology is closely related to basic

research. In manufacturing-intensive industries, however, the gap between basic research and commercial products is often quite large. Research breakthroughs only set the stage for the effort to master the manufacturing processes and achieve the economies of scale that are necessary for commercial success. Consequently, for industries such as electronics, generic technology is more closely related to manufacturing processes and materials than to basic research.

Public policy officials and managers alike are still trying to understand generic and precompetitive technology and to develop policies and programs to promote them. Nonetheless, such programs as Sematech and the Advanced Technology Program at the National Institute of Standards and Technology (NIST) indicate that the government clearly recognizes it must work with the private sector to advance critical generic technologies. President Bush affirmed this concern in his March 7, 1990 speech to the American Electronics Association, when he stated:

> "This Administration is committed to working with you in the critical precompetitive development stage where the basic discoveries are converted into generic technologies that support both our economic competitiveness and our national security."

This policy was strongly affirmed by a landmark White House report, *U.S. Technology Policy*, issued by the OSTP in September 1990. This report represents a watershed in thinking about the impact of technology on America's competitiveness. It outlined, for the first time, a federal technology policy — as contrasted to a science policy — and acknowledged that the federal government must take into account the challenges American industry faces in international markets. It states that the government has the responsibility to "...participate with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications."

This message represents a major step forward. The Bush Administration has outlined its technology policy. It is now the responsibility of U.S. industry, labor and higher education to engage in a constructive dialogue with government about how to implement this policy in ways that will secure America's future competitiveness.

The President's statement and the OSTP report represent a crucial recognition of the government's responsibility to work with the private sector to ensure U.S. technological leadership in key technologies that support U.S. competitiveness. Although some claim that the government is unable to make intelligent choices when it comes to supporting critical technology, the government has long been deeply involved in the process of choosing R&D projects for support. In 1990 alone, the NSF funded about 17,000 research projects whose value was determined on the basis of the peer review system, and the NIH provided about 34,000 research grants. In addition, the United States has a long tradition of funding major national technology projects, from land-grant colleges with their focus on agricultural R&D to the space program, the Human Genome project and the Superconducting Supercollider. Clearly, the issue is not whether the government can cooperate with the private sector to choose meaningful technology projects for support. It can and already does. Instead, the issue is whether the U.S. government adequately takes into account issues related to competitiveness in making these decisions.

It is important to recognize, however, that research alone is not enough. In order to have a significant impact on U.S. competitiveness, government R&D must be supported by policies that help pull technology into the market. In the past, U.S. infrastructure projects, defense procurement and national missions have all signaled potential market opportunities and facilitated

large-scale private-sector investments. Today, however, many U.S. government technology programs have become overly specialized and have lost their relevance for commercial markets. As a result, they do not adequately stimulate related private-sector investments in technology and help pull new technology into the market.

If federal R&D programs provide a research push to emerging technology and national missions provide a market pull for new applications, the overall economic climate affects industry's ability to make the necessary investments. For technology programs to have a major impact on U.S. industrial competitiveness, they must be complemented by appropriate tax, trade and regulatory policies that promote private-sector investment in technology. This is not to say that the federal government alone is responsible for America's technological competitiveness. What the government can do is sponsor research, provide the necessary infrastructure and create an environment that is conducive to private-sector investment. In the end, it is up to industry to take the risks, make the investments, provide the management and master the manufacturing processes necessary to commercialize technology effectively.

In the past, U.S. science and technology policy has not given much emphasis to generic technologies that have the potential to contribute to a broad range of commercial applications. It did not have to. The United States enjoyed worldwide technological superiority, and the rapid commercialization of new ideas was not a major factor in the marketplace. Intense international competition changed all that. It created a premium on the development, use and rapid commercialization of technology. In the decade ahead, issues related to technological leadership will increasingly preoccupy public policy officials, business executives, university administrators and labor leaders. The OSTP report, *U.S. Technology Policy,* clearly recognizes this new priority. The challenge is to make sure that this new priority is widely communicated throughout the public and private sectors and that U.S. programs and funding priorities adequately address it.

Technology and National Security

Growing international competition in technology-intensive industries has raised questions not only about economic competitiveness, but also about U.S. national security. Because many U.S. industries that are critical to national defense — such as electronic components, machine tools and integrated circuit fabrication equipment — were undermined by foreign competition during the 1980s, the Department of Defense now finds itself dependent on foreign suppliers for many strategic technologies. This dependency highlights just how closely defense technology and commercial technology are related. Of the 22 key technologies the Department of Defense identified in its 1989 *Critical Technologies Plan*, 16 overlap with the emerging technologies that the Department of Commerce identified in its 1990 *Emerging Technologies Report.* As a result of this overlap, American industry's commercial technology problems quickly become national security headaches. This realization has focused attention on the fact that industrial technology and the health of the U.S. technology base are now dominant factors in national security. (For comparisons of the Defense and Commerce Department lists, as well as lists prepared by the Japanese and Europeans, see the discussion in Chapter III and Appendix II.)

In the absence of a government agency that can bolster U.S. industry's technological performance, the Defense Department has served as America's primary technology agency. In Japan, the Ministry of Trade and Industry focuses R&D on such fields as hypersonic aircraft, supercomputers and semiconductors. In the United States,

the Defense Department carries out analogous programs. Its support for dual-use technologies that benefit both military and civilian industries has been a hallmark of U.S. defense policy since the end of World War II. This policy has served the country well. The computer industry, the electronic components industry, the machine tool industry and others have all benefited from military R&D programs.

But over time, defense technology programs and market circumstances have changed. Today, many of the U.S. industries that have benefited from defense technology programs are threatened by foreign competition. Moreover, it is also doubtful that defense technology programs, as currently structured, will provide as many industrial benefits to the country in the future as they have in the past. The major shifts in the Defense Department's role are summarized in Table 4. Three issues deserve consideration.

First, the commercial sector will increasingly drive the strategic technologies of the future. During much of the postwar era, the Defense Department spearheaded many of the technology breakthroughs that paved the way for private industry commercialization efforts. There is mounting evidence that this trend is changing. Today's leading-edge technologies in microelectronics, computers and telecommunications are found, not in Defense Department laboratories, but in private industry. Moreover, consumer products, not industrial products, are frequently

Table 4
THE DEFENSE DEPARTMENT'S CHANGING ROLE IN TECHNOLOGY DEVELOPMENT

1950s	TODAY
Defense technology more advanced than civilian technology.	Civilian technology more advanced than much defense technology.
Defense R&D highly relevant to commercial industry.	Defense R&D increasingly specialized and of limited relevance to commercial industry.
Flexible policies allow defense procurement to facilitate the development of new technology-intensive industries.	Rigid policies render defense procurement of limited value for new technology-intensive industries.
Defense technology standards consistent with many industrial needs.	Defense military-specifications at odds with industrial practices and irrelevant to industrial needs.
Defense export controls acceptable because of U.S. industry's technological dominance.	Defense export controls are often ineffective and undermine U.S. industrial competitiveness because of worldwide distribution of technological competence in many industries.
Defense R&D creates breakthroughs that advance U.S. industrial performance.	Defense R&D does not contribute to the integrated process improvements driving international competition in many industries.

Source: Council on Competitiveness

driving state-of-the-art technology, as the video camcorder so clearly demonstrates. Instead of industry adapting defense technology breakthroughs to commercial markets, the Defense Department is increasingly adapting commercial technology to its needs.

Second, the Defense Department's technology practices are more often at odds with successful commercial practices. When the United States enjoyed undisputed international dominance in technology, the Pentagon forced a strict separation of defense and commercial applications in an attempt to keep key military technology out of the hands of America's adversaries, and it backed this separation with tough export controls. As a result, the U.S. defense industry lost touch with the relentless push for improvement and the manufacturing excellence that characterize competition in commercial markets, and many U.S. commercial manufacturers were denied access to important foreign markets. Cost-plus contracts, quality control based on inspection rather than process improvement, highly specialized products, limited production runs and restricted markets are the dominant features of defense technology management. By contrast, flexibility, high quality at low cost, volume manufacturing expertise and access to many different markets are the primary concerns of managers in the private sector.

Third, the status of the defense budget is in flux. Political changes in the Soviet Union and Eastern Europe have put pressure on the Defense Department to scale back its budget, including its basic and applied research (line items 6.1 and 6.2 in the DOD budget), which are especially relevant to industry, but which failed to grow during the big defense build-up of the 1980s. The Iraq war, however, has highlighted another kind of military threat and prompted a reevaluation of plans to reduce military spending significantly. When the Iraq crisis is over, there may be a renewed effort to reduce military spending, but it is difficult to predict what the final outcome will be. For the time being, then, it is uncertain what kind of resources the Pentagon will have at its disposal to promote R&D that will have benefits for industry.

Conclusion

In today's highly competitive world markets, government support for basic science and military technology programs is no longer sufficient to ensure a strong U.S. technology base. Global competition in technology-intensive industry, rising costs for the development of new technology and a changing DOD role are forcing both the private sector and government to rethink their priorities. Business as usual will not suffice. U.S. industry must focus on the commercialization and integration of new technologies. Government must make competitiveness and technological leadership a national priority. The chapters that follow examine the generic enabling technologies that will drive national economic performance in the decade ahead.

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[1] Bureau of Economic Analysis, U.S. Department of Commerce.

[2] For a complete discussion of federal science and technology policies and U.S. competitiveness, see *Picking Up the Pace*, the Council on Competitiveness, September 1988.

[3] *SEMATECH 1990*, A Report to Congress by the Advisory Council on Federal Participation in Sematech, May 1990.

[4] The Department of Commerce, *The Status of Emerging Technologies: An Economic/Technological Assessment to the Year 2000*, Spring 1987.

The Department of Commerce, *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Spring 1990.

[5] The Department of Defense, *Critical Technologies Plan*, March 15, 1989, revised May 5, 1989.

The Department of Defense, *Report to Congress on the Defense Industrial Base: Critical Industries Planning*, October 1990.

The Office of Science and Technology Policy, Forthcoming Report on Critical Technologies.

CHAPTER II

ASSESSMENT OF CRITICAL TECHNOLOGIES

A central objective of this project was to address three fundamental questions:

- Which technologies are important to U.S. industry's performance in the next decade?
- What is America's competitive position in these technologies?
- Where does the United States need to improve its performance?

To identify the technologies that will drive industry's performance in the next decade, the Council on Competitiveness worked closely with senior technology experts from nine sectors of U.S. industry to identify the technologies that were critical to each industry. The nine sectors were: 1) aerospace, 2) chemicals and allied products, 3) computers and software, 4) construction, 5) drugs and pharmaceuticals, 6) electronic components and equipment, 7) machine tools, 8) motor vehicles, and 9) telecommunications. These sectors represent a broad cross section of the American economy. They include industries with substantial trade surpluses and deficits, industries in both defense and civilian markets, industries with rapid and slow product cycles, industries with vast differences in their approach to and support of R&D activities and industries representing manufacturing, life sciences, services and information processing. Together, they account for over $1 trillion in sales and employ about 12 million people. Their scope and diversity provided rich insights into America's strengths and weaknesses in the development and application of technology. The Council verified the list of critical technologies prepared by each sector with leading executives from universities, labor unions, others in industry and other specialists. The Council then combined the technologies from all of the sectors into a master list and verified this new list with a broad group of experts. The result was a core group of technologies that are basic to the performance of most major U.S. industrial sectors. (For further discussion of how the report was prepared, see "About the Project." For a profile of each of the nine industrial sectors, see Appendix I.)

For each technology, the Council also assessed whether the U.S. competitive position was strong, competitive or weak — or if the United States was no longer in the market. And for each technology, the Council examined the factors, including both public policies and industry practices, that influence U.S. performance.

As a result, the Council was able to determine what a broad spectrum of U.S. industry thinks about critical technologies, where U.S. industry stands, what the United States is doing well and what needs to be improved.

The Council's analysis differs from previous studies in that it focuses on the needs of a broad spectrum of U.S. industries rather than on the needs of particular industries or government agencies. And it focuses on the technologies that will be important over the next 10 years, rather than ones with more distant applications.

Critical Technologies for U.S. Industrial Competitiveness

The sole criterion for choosing the following technologies is their importance for the competitiveness of the industrial sectors studied. The Council defined technology fairly broadly to include some organizational technologies and some underlying fields of knowledge. The technologies that the nine industrial sectors identified as critical include both technologies with well-established markets and technologies with emerging markets.

The technologies identified as critical to industrial competitiveness fall into five groups: **1) materials and associated processing technologies, 2) engineering and production technologies, 3) electronic components, 4) information technologies** and **5) powertrain and propulsion technologies.** The first four groups are arranged from the more "upstream" materials and processes to the more "downstream" components and systems. The fifth group is critical to the motor vehicle and aerospace industries.

1. Materials and Associated Processing Technologies

MATERIALS AND ASSOCIATED PROCESSING TECHNOLOGIES

Advanced Structural Materials
- Advanced Metals
- Metal Matrix Composites
- Polymers
- Polymer Matrix Composites
- Structural Ceramics

Electronic and Photonic Materials
- Display Materials
- Electronic Ceramics
- Electronic Packaging Materials
- Gallium Arsenide
- Magnetic Materials
- Optical Materials
- Photoresists
- Silicon
- Superconductors

Biotechnologies
- Bioactive/Biocompatible Materials
- Bioprocessing
- Drug Discovery Techniques
- Genetic Engineering

Materials Processing
- Catalysts
- Chemical Synthesis
- Membranes
- Net Shape Forming
- Precision Coating
- Process Controls

Environmental Technologies
- Emissions Reduction
- Recycling/Waste Processing

Source: Council on Competitiveness

New materials are driving advances in products and processes that are critical to all nine sectors the Council studied.

Advanced Structural Materials

These materials can make products stronger, lighter and more effective, and they can enable

the development of totally new products. For example, they lead to better-performing and more fuel-efficient automobiles and airplanes and more durable equipment. These materials can increasingly be designed and tailored to specific applications.

Electronic and Photonic Materials

These materials are vital to advances in semiconductors and other electronic components. Silicon and electronic packaging materials are critical to virtually all advanced electronics. Close links between material developers and users in the electronics, aerospace and automobile industries are key to providing a demand for advanced materials that drives innovation.

Biotechnologies

Advances in biomaterials and bioprocessing are enabling advances in medicine, agriculture and chemicals. Biotechnology appears less prominently on the Council's list than on other groups' critical technologies lists for two reasons. First, it is less a distinct technology than a set of diverse research techniques and processing technologies. Biotechnology research techniques have become an integral part of biochemical research, and it is this broader research base that is critical to the pharmaceutical and other industries. Second, although the economic impact of biotechnologies is expected to be large, it is not expected to be significantly greater in the next decade than that of many other technologies, such as electronic and structural materials.

The discovery of new materials is closely related to basic scientific research, particularly in biology, chemistry and the physics of materials. Conversely, advances in technology, such as new ways of manipulating molecules, more powerful scientific instruments and better data manipulation capabilities are essential to advances in science. Cooperative university-industry-government relations, the availability of highly trained and talented research personnel and strong intellectual property protection are critical to success in developing new materials. Equally critical to success in materials are processing and environmental technologies.

Materials Processing

These technologies create the ability to produce low-cost and high-quality materials. If a company lags behind in materials processing, it is likely to lose market share, which will prevent it from being able to invest in new products.

Environmental Technologies

Closely related to materials processing are a number of environmental technologies. Because these technologies are often driven by regulatory requirements, many companies must master them just to stay in business. And because environmental concerns are growing around the world, being able to exploit environmental technologies can lead to success in new markets as well as a competitive edge in existing markets.

2. Engineering and Production Technologies

ENGINEERING AND PRODUCTION TECHNOLOGIES

Design and Engineering Tools
- Computer-Aided Engineering
- Human Factors Engineering
- Leading-Edge Scientific Instruments
- Measurement Techniques
- Structural Dynamics
- Systems Engineering

Commercialization and Production Systems
- Computer-Integrated Manufacturing
- Design for Manufacturing
- Design of Manufacturing Processes
- Flexible Manufacturing
- Integration of Research, Design and Manufacturing
- Total Quality Management

Process Equipment
- Advanced Welding
- High-Speed Machining
- Integrated Circuit Fabrication and Test Equipment
- Joining and Faste[illegible]n Technologies
- Precision Bearin[illegible]
- Precision Machining
- Robotics and Automated Equipment

Source: Council on Competitiveness

The equipment and processes needed to develop and produce products are critical to every industry. These include the tools and techniques needed to design and engineer products and processes, the organizational technologies of managing the commercialization and production processes, and the equipment used in production.

Design and Engineering Tools

Computer-aided design and engineering are critical in virtually every industry. Applications range from designing molecules to engineering buildings. Computer-aided design tools are also essential in designing microelectronic circuits and automobiles. In consumer products, superior design and engineering are key sources of competitive advantage. More powerful scientific instruments are opening many of the advances in the sciences that are making possible new materials.

Commercialization and Production Systems

"Organizational" technologies fall outside a narrow definition of technology but are unquestionably "critical." The organization of a production plant often has a greater influence on productivity than any production equipment. For example, many Japanese automobile plants achieve high productivity with only moderate amounts of automation, whereas some highly automated U.S. plants have been poor performers. Equally important are the processes by which organizations learn to improve their productivity. The organizations that continually improve are the ones that will succeed in the long run.

Systems of commercializing technology are equally important. A company that is a year behind its leading competitors in technology but is two years faster than its competitors in getting a product from the design stage to the market will have a one-year head start in getting technology into the marketplace. Knowing how to integrate the research, design and manufacturing processes is one of the most important technologies. Computer-integrated manufacturing systems are emerging as a critical part of this integration process.

Process Equipment

A variety of process equipment — including precision machining and forming, robotics and other automated equipment, and various joining and fastening technologies — is also critical to a broad range of industries. Integrated circuit fabrication and test equipment is particularly important because of the importance of integrated circuits to the national economy.

The United States has performed poorly in many areas of manufacturing systems and equipment. Part of the poor performance reflects a long-standing underemphasis on manufacturing. Without U.S. manufacturers leading the demand for state-of-the-art equipment, it was difficult for equipment manufacturers to maintain technological leadership. In addition, many equipment producers have found it difficult to sustain investment in R&D; because many are smaller companies they have been unable either to afford the investment or to withstand the cyclical demand for their equipment.

3. Electronic Components

ELECTRONIC COMPONENTS

- **Microelectronics**
  - Logic Chips
  - Memory Chips
  - Microprocessors
  - Submicron Technology
- **Electronic Controls**
  - Actuators
  - Sensors
- **Optoelectronic Components**
  - Laser Devices
  - Photonics
- **Electronic Packaging and Interconnections**
  - Multichip Packaging Systems
  - Printed Circuit Board Technology
- **Displays**
  - Electroluminescent
  - Liquid Crystal
  - Plasma and Vacuum Fluorescent
- **Hardcopy Technology**
  - Electro Photography
  - Electrostatic
- **Information Storage**
  - Magnetic Information Storage
  - Optical Information Storage

Source: Council on Competitiveness

Electronic components, and especially microelectronics, play a pivotal role in the nation's economy. Electronic components are the core parts of the electronic and information systems that are essential to all nine sectors the Council examined. These components have been identified by many nations as strategic technologies with applications in many defense and commercial products. Rapid improvements in electronic components are playing an especially important role in driving improvements in information and communication technologies, which in turn are enabling advances in all manufacturing and service industries.

Microelectronics

Microprocessors, logic chips (e.g., ASICs) and memory chips (e.g., DRAMs and EPROMs) are the brains and memories of information technologies and are thus directly or indirectly essential to virtually all industries.[1]

Electronic Controls

Electronic controls are increasingly critical to the operation of airplanes, automobiles, industrial machinery and materials processing. Within automobiles, for example, they are essential elements of cleaner and more fuel-efficient engines, antiskid braking systems and a large number of other systems.

Optoelectronic Components

Laser and light-emitting diodes, and optical fibers are critical for improved telecommunication systems and a variety of computer applications and for saving weight in airplanes and automobiles.

Electronic Packaging and Interconnections

Improvements in both integrated-circuit-to-package and board-to-board packaging can reduce the size and improve the performance of electronic devices. They also can lower costs and

improve the reliability of electronics, particularly under extreme conditions.

Displays

Improvements in both flat panel and cathode ray tube displays can enable a large number of new electronics applications, including more portable systems and systems with better image quality.

Hardcopy Technology

Improvements in a variety of printing and scanning technologies promise to reduce the cost and improve the performance of information systems.

Information Storage

Optical and magnetic data storage technologies also are critical elements of information systems that are becoming increasingly important to all sectors of the economy.

Microelectronic technologies are characterized by high developmental and capital costs, declining marginal costs of production, rapid product cycles incorporating incremental improvements and steep business cycles. The increasing amount of capital required for successive generations of products creates barriers to entry for latecomers; thus, companies with large market shares have advantages in developing the next generation of products.

Both the level of innovation and the capability to produce high-quality and reliable components at low cost are key to success in these technologies. Innovation depends on basic and applied research and on skilled research and engineering personnel. State-of-the-art process equipment and electronic materials (areas where the United States is weak) are critical to manufacturing. Access to capital and an ability to share risk across different lines of business are critical to allowing companies to survive business cycles and continue to invest in technologies. Computer-aided design and engineering tools are also key to product development.

4. Information Technologies

INFORMATION TECHNOLOGIES

Software
- Applications Software
- Artificial Intelligence
- Computer Modeling and Simulation
- Expert Systems
- High-Level Software Languages
- Software Engineering

Computers
- Hardware Integration
- Neural Networks
- Operating Systems
- Processor Architecture

Human Interface and Visualization Technologies
- Animation and Full Motion Video
- Graphics Hardware and Software
- Handwriting and Speech Recognition
- Natural Language
- Optical Character Recognition

Database Systems
- Data Representation
- Retrieval and Update
- Semantic Modeling and Interpretation

Networks and Communications
- Broadband Switching
- Digital Infrastructure
- Fiber Optic Systems
- Multiplexing

Portable Telecommunications Equipment and Systems
- Digital Signal Processing
- Spectrum Technologies
- Transmitters and Receivers

Source: Council on Competitiveness

Information technologies are increasingly critical to the competitiveness of all nine industries that the Council examined, with applications in the design of products, manage-

ment of production processes and improvement in the performance of products. They are especially important to the growing service sectors of the economy. For example, they are central to the telecommunications sector and are critical for the construction industry.

Software

Software is critical to every industry that we studied. Nearly every industry uses a wide variety of applications software, and most use computer modeling and simulation software to improve the design of their products and production processes. Industries are increasingly using various aspects of artificial intelligence to give computers increasing capability and to make "smarter" products.

Computers

Increasingly advanced computers are critical to running this software. Advances in processor architecture, including parallel processing, and hardware integration are key to these advances. Neural networks have the potential to expand the use of computers into new tasks.

Human Interface and Visualization

These technologies are of emerging importance to the computer industry and are expected to be important to other industries as well. Graphics, animation, and speech and character recognition are expected to increase the usefulness of computers in many areas.

Database Systems

Advanced databases are essential to all industries that need to manage or access large amounts of data. For instance, in the pharmaceutical industry they are used to keep track of and access research results; in the construction industry they are used to keep track of building codes and project inventories.

Networks and Communications

These systems are critical to the telecommunications industry, which in turn is critical to many information-intensive industries.

Portable Telecommunication Equipment and Systems

These technologies are critical to increasing the performance and availability of mobile telecommunications.

The United States is generally strong in the knowledge-intensive areas, such as computer architecture, systems integration and software. Continued success in these areas depends on skilled and creative personnel, effective intellectual property protection and U.S. leadership in standards. It also depends on the availability of electronic components, which constitute the dominant portion of the hardware value in information technologies. The U.S. strength in information technologies is vulnerable to the U.S. weakness in these components.

5. Powertrain and Propulsion Technologies

POWERTRAIN AND PROPULSION TECHNOLOGIES

Powertrain
- Alternative Fuel Engines
- Electric Motors and Drives
- Electrical Storage Technologies
- High Fuel Economy/Power Density Engines
- Low Emission Engines

Propulsion
- Airbreathing Propulsion
- Rocket Propulsion

Source: Council on Competitiveness

Powertrain and propulsion technologies are unlike the previous categories in that they are primarily used in single sectors, namely, motor vehicles and aerospace. They are "critical technologies" nonetheless because of their central role in these industries, which in turn are major drivers and consumers of materials, production and information technologies. Thus U.S. performance in these technologies has significant economic consequences. Advances in materials, electronic controls and computer-aided engineering underlie many of the advances in powertrain and propulsion technologies.

Lessons

The Council's assessment of critical technologies yielded three overall lessons:

■ There is an identifiable core group of technologies that is vital to the overall competitiveness of U.S. industry. Advances in materials, engineering and production, electronics and information systems are driving innovations and superior performance in every industry.

■ The technologies that are most important to industry include not only emerging technologies that will create new industries, but also technologies that will improve performance in existing industries. Many of the most important technologies for industrial competitiveness are not dramatic breakthroughs, such as high-temperature superconductors, but are incrementally evolving technologies, such as materials processing and the design of manufacturing systems.

■ Organizational systems of managing the design, commercialization and production process are key areas of knowledge for companies to master. That is, not all critical technologies involve hardware or computer software. Many involve human know-how.

U.S. Competitive Position in Critical Technologies

The Council categorized the U.S. position in each of the technologies in one of four ways:

- **Strong** — U.S. industry is in a leading world position and is not in danger of losing this position in the next five years.
- **Competitive** — U.S. industry is roughly at par with world-best. This category includes technologies where the United States is leading but the leadership is unlikely to be sustained over the next five years, technologies where the United States is at par and staying even and technologies where different countries lead in different niches.
- **Weak** — U.S. industry is behind in technology or likely to fall behind in the next five years. Changes are needed if the United States is to remain in the businesses relating to this technology.
- **Losing Badly or Lost** — U.S. industry is no longer a factor or is not likely to have a presence in the next five years. It will take considerable effort or a major change in technology for the United States to become competitive.

In general, the competitive position is the status of technologies that are incorporated in products or processes already in the marketplace, rather than the technologies in the laboratory. If a technology has not yet been commercialized (such as superconductors), the competitive position reflects the status of research and development. The assessments represent the overall judgment of experts in industry who understand both the technologies and the markets, and take into account the fact that the competitive position is often different for subsets of the technology. For example, although the United States is generally losing in memory chips, U.S. companies are competitive in some niches.

The U.S. competitive position in critical technologies is shown in the following charts.

Technologies in which the United States is Strong

TECHNOLOGIES IN WHICH THE UNITED STATES IS STRONG

Materials and Associated Processing Technologies
- Bioactive/Biocompatible Materials
- Bioprocessing
- Drug Discovery Techniques
- Emissions Reduction
- Genetic Engineering
- Recycling/Waste Processing

Engineering and Production Technologies
- Computer-Aided Engineering
- Systems Engineering

Electronic Components
- Magnetic Information Storage
- Microprocessors

Information Technologies
- Animation and Full Motion Video
- Applications Software
- Artificial Intelligence
- Computer Modeling and Simulation
- Data Representation
- Data Retrieval and Update
- Expert Systems
- Graphics Hardware and Software
- Handwriting and Speech Recognition
- High-Level Software Languages
- Natural Language
- Neural Networks
- Operating Systems
- Optical Character Recognition
- Processor Architecture
- Semantic Modeling and Interpretation
- Software Engineering
- Transmitters and Receivers

Powertrain and Propulsion
- Airbreathing Propulsion
- Low Emission Engines
- Rocket Propulsion

Source: Council on Competitiveness

The technologies where the United States is strong are generally areas where the private sector has aggressively invested in technology and where the U.S. policy environment has been supportive.

The strong U.S. position in biotechnology, for example, is directly related to the combination of three elements: the intensity of the U.S. pharmaceutical industry's commitment to research; significant federal support of biological research, particularly by the National Institutes of Health; and the relatively unfettered flow of information between government-supported and industry researchers. U.S. government-supported research, which greatly exceeds that by any other country, contributed substantially to the creation of modern biotechnology.

The favorable U.S. position in several environmental technologies is traceable to the strong demand for these technologies created by domestic regulations. Although this demand creates an advantage for U.S. companies in exploiting these technologies, companies from other countries are also moving quickly to meet the demand.

The strong U.S. position in a number of computer-related technologies reflects the historically powerful U.S. computer industry, which was supported in its early days by Department of Defense research and procurement and has sustained its lead due to leading-edge U.S. university and computer industry research. A climate that supports entrepreneurship has also aided the U.S. position in many of these technologies.

The strong U.S. position in propulsion technologies is largely due to steady and significant federal procurement of products using these technologies, experience in systems expertise, high barriers to entry for newcomers to the field and significant investments in aerospace and defense research.

The fact that the United States remains strong in these technologies is not a cause for complacency. In many of these technologies, the U.S. lead is diminishing, and in virtually no cases is the U.S. lead significantly increasing.

Technologies in which the United States is Competitive

TECHNOLOGIES IN WHICH THE UNITED STATES IS COMPETITIVE

Materials and Associated Processing Technologies
- Catalysts
- Chemical Synthesis
- Magnetic Materials
- Metal Matrix Composites
- Net Shape Forming
- Optical Materials
- Photoresists
- Polymers
- Polymer Matrix Composites
- Process Controls
- Superconductors

Engineering and Production Technologies
- Advanced Welding
- Computer Integrated Manufacturing
- Human Factors Engineering
- Joining and Fastening Technologies
- Measurement Techniques
- Structural Dynamics

Electronic Components
- Logic Chips
- Sensors
- Submicron Technology

Information Technologies
- Broadband Switching
- Digital Infrastructure
- Digital Signal Processing
- Fiber Optic Systems
- Hardware Integration
- Multiplexing
- Spectrum Technologies

Powertrain and Propulsion
- Alternative Fuel Engines
- Electrical Storage Technologies
- Electric Motors and Drives

Source: Council on Competitiveness

There is no clear pattern to the technologies where the United States is competitive. Because these technologies are ones in which the United States is roughly at par with the best of the world, there are not easily identifiable factors in the policy or economic environment that either help or hurt U.S. industry in these areas.

These technologies include those, such as logic chips and photoresists, in which the United States once dominated but others have caught up. They also include technologies, such as optical materials, in which different countries lead in different market niches. Other technologies, such as superconductors and submicron technology, are still in the research stage, and no clear leader has been established.

A number of these technologies are integral to a few large and robust U.S. industries, such as chemicals, automobiles and telecommunications, and the resources of these industries help keep the United States competitive in the underlying technologies.

Here, too, the trends are not encouraging. The U.S. position has been declining in many technologies and has not been improving in any.

Technologies in which the United States is Weak

TECHNOLOGIES IN WHICH THE UNITED STATES IS WEAK

Materials and Associated Processing Technologies
- Advanced Metals
- Membranes
- Precision Coating

Engineering and Production Technologies
- Design for Manufacturing
- Design of Manufacturing Processes
- Flexible Manufacturing
- High-Speed Machining
- Integration of Research, Design and Manufacturing
- Leading-Edge Scientific Instruments
- Precision Bearings
- Precision Machining and Forming
- Total Quality Management

Electronic Components
- Actuators
- Electro Photography
- Electrostatics
- Laser Devices
- Photonics

Powertrain and Propulsion
- High Fuel Economy/Power Density Engines

Source: Council on Competitiveness

Many of the areas where the United States is weak reflect the effects of high capital costs; the lack of cooperative relations between equipment, materials and component suppliers and their customers; and an underemphasis on manufacturing.

Many of the materials and electronic component technologies are capital-intensive and are characterized by rapid product cycles and pronounced business cycles. In many cases, the U.S. industry is made up of many autonomous, often smaller, companies that have limited financial resources and have historically not cooperated with upstream or downstream companies to share risks in R&D. As a result, they have been more vulnerable to business cycles than their overseas competitors and have been less able to sustain investments in technologies.

Weaknesses in many engineering and production technologies reflect a pervasive underemphasis on manufacturing in the United States. Many U.S. industries have lost market share because they were unable to produce as high-quality and reliable products as their competitors do.

U.S. manufacturers have also failed to lead the demand for new manufacturing technologies. Without U.S. manufacturers leading the demand for state-of-the-art equipment — and without U.S. equipment manufacturers participating in the markets that demanded the most advanced equipment — U.S. equipment manufacturers were not pressured to stay up with the state of the art.

Technologies in which the United States is Losing Badly or Has Lost

TECHNOLOGIES IN WHICH THE UNITED STATES IS LOSING BADLY OR HAS LOST

Materials and Associated Processing Technologies
- Display Materials
- Electronic Ceramics
- Electronic Packaging Materials
- Gallium Arsenide
- Silicon
- Structural Ceramics

Engineering and Production Technologies
- Integrated Circuit Fabrication and Test Equipment
- Robotics and Automated Equipment

Electronic Components
- Electroluminescent Displays
- Liquid Crystal Displays
- Memory Chips
- Multichip Packaging Systems
- Optical Information Storage
- Plasma and Vacuum Fluorescent Displays
- Printed Circuit Board Technology

Source: Council on Competitiveness

The areas where the United States is losing badly or has lost show similar characteristics to those where the United States is weak: high capital costs, industry fragmentation and underemphasis of manufacturing. In addition, many of the areas where the United States has lost are areas where concentrated foreign efforts have hurt the competitiveness of U.S. industry. For example, several technologies — such as microelectronics, digital infrastructure and advanced materials — are ones that other countries have identified as critical and have supported in a focused way, often using a variety of trade and investment policies.

It should be noted that even in areas where the United States is losing badly, U.S. companies may be successful in some niches. For example, although the U.S. industry is in general losing badly in memory chips, a few companies have substantial in-house capabilities, and U.S. merchant firms are successul in some small niches, such as erasable programmable read only memories (EPROMs) and static random access memories (SRAMs).

Lessons

Several conclusions can be drawn from an examination of the U.S. position in these technologies.

First, the strong U.S. position of a decade ago has deteriorated significantly. U.S. industry has already lost several technologies that are critical to industrial performance and is losing badly in several others.

Second, many areas of U.S. strength have the following characteristics:

- They are close to basic research or are the direct result of basic research without the intervening steps of lengthy technology development (e.g., biotechnologies).
- They do not have heavy capital investment needs (e.g., software).
- They can be initiated largely by individual innovation (e.g., computer-aided engineering).
- They are strongly supported by U.S. government investment in basic research (e.g., genetic engineering), defense procurement (e.g., rocket propulsion) and environmental regulations (e.g., emissions reduction).
- They have been supported by high levels of private-sector R&D (e.g., materials and information technologies).

Third, many of the areas where the United States is weak or has lost have the following characteristics:

- They have not had sufficient private or public investment in the underlying technology (e.g., display materials).
- There is inadequate risk-sharing among companies in technology development (e.g., electronic packaging).
- They have high capital needs and low capital investment (e.g., automated equipment).
- They need extensive investment in technology for an extended period of time (e.g., optical information storage).
- They have a significant manufacturing focus (e.g., integrated circuit fabrication equipment).
- They have been targeted by foreign government and industry (e.g., memory chips).

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[1] ASICs are application-specific integrated circuits, DRAMs are dynamic random access memories and EPROMs are erasible programmable read only memories.

CHAPTER III

INTERNATIONAL COMPARISON OF CRITICAL TECHNOLOGIES

The United States, Japan and Europe each has identified essentially the same set of critical technologies. But each has different programs to promote them.

Comparison of Critical Technologies

The Council's critical technologies overlap significantly with those identified by several other groups, including the U.S. Department of Commerce,[1] the U.S. Department of Defense,[2] the Japanese Ministry of International Trade and Industry (MITI)[3] and the European Community (EC).[4] Each list has the same general purpose: to focus and prioritize efforts to develop technology.

The emphasis on setting technology priorities is a recent phenomenon, both in the United States and abroad. For decades, the United States had a sufficiently large lead over the rest of the world in civilian technologies that it did not need to directly support technology development. U.S. companies could reap most of the benefits of U.S.-funded basic research and defense R&D, and these benefits seemed sufficient to keep U.S. industry ahead of the rest of the world. Japan and Europe also had little need to prioritize technologies until recently, because the technological path was clear: follow and catch up with the United States. Today, many countries are technologically on a par with the United States in many areas, and basic research and defense R&D — traditional U.S. strengths — are no longer sufficient to maintain a U.S. lead in technology. As a result, the United States, along with its chief competitors, has placed a new emphasis on setting priorities for technology development — for identifying areas of particular needs and opportunities.

Although the lists have similar purposes, each has a different emphasis. The Department of Defense list focuses on defense technologies and therefore excludes many commercially important areas, such as environmental technologies. The Department of Commerce list focuses on emerging technologies and thus emphasizes technologies with expected future growth, such as superconductors, rather than technologies that are critical to improving competitive performance in existing industries, such as materials processing.

The MITI list emphasizes fundamental technologies — such as materials, components

INTERNATIONAL COMPARISON OF CRITICAL TECHNOLOGIES

COUNCIL'S TECHNOLOGIES	OTHER ORGANIZATIONS			
	DOD	DOC	MITI	EC
Materials and Associated Processing Technologies				
Advanced Structural Materials	■	□	■	■
Electronic and Photonic Materials	■	■	■	■
Biotechnologies	■	■	■	■
Materials Processing	□	□	■	■
Environmental Technologies			■	□
Engineering and Production Technologies				
Design and Engineering Tools	□	□	■	□
Commercialization and Production Systems	□	■	□	■
Process Equipment	□	□	■	■
Electronic Components				
Microelectronics	■	■	■	■
Electronic Controls	□	■	□	
Optoelectronic Components	■	■	■	■
Electronic Packaging and Interconnections	□			
Displays		■		■
Hardcopy Technology				
Information Storage		■		■
Information Technologies				
Software	■	■	■	■
Computers	■	■	■	■
Human Interface and Visualization Technologies		□		
Database Systems	■			
Networks and Communications				■
Portable Telecommunications Equipment and Systems				
Powertrain and Propulsion Technologies				
Powertrain				□
Propulsion	■			■

Notes: ■ = direct correlation.
□ = indirect correlation, i.e., included as part of a larger category.

Source: Council on Competitiveness

and processes — and generally excludes systems that are made up of more fundamental technologies. For this reason, the MITI list does not include a number of electronic subsystems, such as displays, that are included on the Council's list. The EC technologies are not drawn from a specific critical technologies list, but are the key areas of research needed for industrial competitiveness identified in the Commission of the European Communities' 1988 report.

The above chart compares other organizations' critical technologies with those of the Council. (A complete version of all these lists appears in Appendix II.)

All but two of the Council's 23 critical technologies appear on at least one other list. Several technologies — including advanced structural materials, biotechnologies, electronic materials, microelectronics, computers and software — appear prominently in all of the analyses. The similarity among the lists is all the more remarkable because of differences in the purposes and perspectives of the studies. The point is clear: when different groups around the world identify the technologies that will be the most important to them in the next decade, they basically come to the same conclusions.

Support for Critical Technologies

There is a wide consensus that to promote commercial technologies within a country, several conditions should be satisfied.

First, R&D must be closely tied to the market. R&D that is isolated from the market is unlikely to meet commercial needs. The "transfer" of technologies developed for noncommercial purposes rarely leads to effective commercial technologies. It is important for R&D projects to be formulated with an understanding of the market needs and to link scientists and engineers with customers and markets.

Second, the funding and results of much precompetitive research should be diffused throughout industry. Because companies cannot capture all of the benefits of such research, individual companies will tend to underfund this research by themselves.

Third, vigorous competition is desirable in proprietary research and product development. Rivalry creates pressures for firms to innovate and continually improve their products and processes.

Programs that do not meet these requirements are likely to be ineffective and inefficient. For example, there is wide agreement that because R&D at U.S. national laboratories is not closely tied to commercial markets, it does relatively little to promote generic industrial technologies.

The boundary between precompetitive research, which thrives on the sharing of information, and proprietary research and development, where companies try to protect their information, varies in different industries and technologies. In some technologies, such as biotechnology, the boundary is close to basic research. In others, such as many manufacturing technologies, the boundary is closer to product development. When the boundary is close to basic research, university funding of basic research is an effective means of conducting all the precompetitive research that an industry needs. But when the boundary is closer to product development, the gap between where basic research ends and proprietary product development begins may be large. For these technologies, substantial cooperation on precompetitive generic technology is needed; strategic consortia involving industry, government and academia can stimulate the necessary research.

The United States has programs in many of the critical technologies, but few are structured to promote commercial technologies. Both Japan and the EC have programs that are specifically designed to promote commercial success in the

key technologies. These programs have been designed around the active participation of industry in the research and development of the technologies.

United States

No line agency of the federal government has broad responsibility for research and other activities related to civilian technology. Responsibility for R&D in the Executive Branch is dispersed among 12 agencies. The primary goals of these agencies are not related directly to the commercialization of technology, and they have tended to subordinate industrially relevant initiatives.

The National Science Foundation (NSF), with an FY1990 budget of over $2 billion, and the National Institutes of Health (NIH), with an FY1990 budget of over $7 billion, fund research related to many areas of critical technology. A large proportion of this research is conducted in universities and medical centers. This research provides substantial benefits to U.S. industry, particularly in areas where basic research contributes directly to technology development, such as pharmaceuticals, chemicals and computer software. In addition to basic research, which to varying degrees translates into commercial applications, the NSF and NIH funding supports the academic and scientific infrastructure for research and funds the training of researchers. The results of the research funded by NSF and NIH, however, are by tradition available equally to researchers and companies anywhere in the world, and foreign, particularly Japanese, companies appear to be accessing this research as well or better than American companies. Thus a central challenge is for American companies and universities to continue to improve their cooperative relations.

Of the Department of Defense R&D budget of $37 billion in FY1990, more than 90 percent went to weapons development, testing and evaluation, which provided little benefit to commercial technologies. About $1.1 billion went to the Defense Advanced Research Projects Agency (DARPA), which conducts most of the more fundamental research that provides the greatest contributions to commercial technologies. This includes funding for Sematech, the semiconductor manufacturing technology consortia.

The National Institute of Standards and Technology of the Department of Commerce is the main U.S. laboratory with a specific mission to support U.S. industry. Its primary mission has been to improve measurement technology, and for many years it had to cope with level or shrinking funding while the demand for its services grew. The recent budget increases and initiatives that expand its role into new areas of technological research, such as the Advanced Technology Program and the Manufacturing Technology Transfer Centers, are major positive shifts in direction and focus. Nevertheless, with a budget of only $170 million in FY1990, its capacity to help industry is limited.

The National Aeronautics and Space Administration (NASA), with an FY1990 budget of about $12 billion, exerts a significant market pull on advanced technologies. Although most of this activity is in support of NASA's missions, $794 million in FY1990 was for aeronautical and space R&D on U.S. military and civilian aviation technologies.

The Department of Energy also has one of the largest R&D budgets — about $7 billion in 1990. Most of this R&D is in support of specific government missions, such as nuclear weapons and energy, but there is a substantial amount of R&D on technologies in areas such as materials. The bulk of this research is conducted within the Department of Energy Laboratories, however, and is isolated from industry. Most of this technology development does not efficiently reach the parts of industry that compete in international markets.

A substantial proportion of federal research is

conducted at federal laboratories. There are 726 of these laboratories established at various times for specific purposes; they have a combined budget of about $20 billion. Over the years, they have expanded and diversified. They focus primarily on defense-related issues and basic research in a few areas, such as energy and health. Although they represent a significant portion of the nation's technical enterprise, they do not focus on supporting the commercial requirements of technology. Recent attempts to get the laboratories to contribute more to commercial technology include the 1986 Technology Transfer Act and Executive Order 12591. There is a consensus among industry, however, that these initiatives have had only a marginal impact.

Although many of the labs seem to have little relevance to industry's needs, some are viewed as doing valuable work, as in biological research. Partly because of this variation, there is no consensus on their scope, mission and relevance to the nation over the next 20 years.

As part of the process of preparing the FY1991 budget, the Office of Management and Budget analyzed federal support across all federal agencies (excluding classified programs) for five advanced technologies. (See table.) The amount and distribution of the funding for these technologies illustrates that although the U.S. government funds a substantial amount of research in technologies of potential commercial importance, only a small portion of it is conducted by NIST, the sole agency with a primary mission of promoting industrial technology. While significant amounts of the research funded by other agencies do contribute to U.S. industrial competitiveness — Sematech, funded by the Department of Defense, and NSF's computer research are noteworthy examples — much does not. For example, although the U.S. government spent around $150 million on robotic research, most of this was to develop a robotic arm for the space station, which has very little application to industrial needs.

AGENCY FUNDING FY1990
($ in millions)

Robotics	
Defense	20
Energy	9
NASA	96
NSF	16
Commerce (NIST)	2
Bureau of Mines	6
Total	150
Superconductivity	
Defense	75
Energy	113
NASA	8
NSF	29
Commerce (NIST)	3
Total	228
High Performance Computing	
Defense	159
Energy	60
NASA	57
NSF	172
Total	448
Advanced Imaging Technologies	
Defense	106
NASA	2
NSF	4
Commerce (NIST)	6
Total	118
Semiconductors	
Defense	423
Energy	45
NSF	53
Commerce (NIST)	4
Total	525

Source: Office of Management and Budget

In addition to the lack of monetary support for technologies of commercial importance, the U.S. government is unsupportive in other ways. Largely because of the federal government's traditional role as regulator, interactions between the public and private sectors have often been adversarial. Moreover, federal law has frequently discouraged cooperation within the private sector. The challenge is to strengthen support for technologies of commercial importance and to build bridges between industry and government.

Japan

Japan funds critical enabling technologies under several programs, including the National Research and Development Program (The Large-Scale Project), the Research and Development Project on Basic Technologies for Future Industries and the Exploratory Research on Advanced Technology Organization (ERATO) program. The National Research and Development Program consists of major projects that last for 6 to 10 years and have annual budgets of $10 to $20 million. They typically involve researchers from several companies. Current or recently completed projects include those on High-Speed Computing Systems, Advanced Robot Technology, Interoperable Database Systems, Advanced Material Processing and Machining Systems, and Super/Hyper Sonic Transport Propulsion Systems. Japan also supports targeted, technology-based industries by means of loans, tax incentives, trade policies, administrative guidance and other policy measures. The Research and Development Project on Basic Technologies for Future Industries consists of 14 projects in four areas: new materials, electronics, biotechnology and superconductivity. The projects typically last for 6 to 10 years and have annual budgets in the $2 to $15 million dollar range. As with The Large-Scale Project, activities are performed cooperatively with industry and government laboratories.

In addition to these MITI projects, there are also projects sponsored by the Key Technology Center (funded jointly with the Ministry of Posts and Telecommunications) and ERATO, under the jurisdiction of the Science and Technology Agency. Several other Ministries also have R&D programs in specific areas, such as biotechnology and superconductivity.

Several key features of Japanese technology programs have contributed to their success. First, the programs are designed specifically to promote economic competitiveness. Industry participates in both the design and execution of the programs to ensure their relevance to industrial needs. Second, they are designed to leverage industrial R&D. The government investment is relatively modest, but the programs stimulate greater investment in proprietary R&D. The private sector funds more than 70 percent of the R&D in Japan, compared with about 50 percent in the United States, where the government spends significantly more on defense R&D. Third, the programs are structured to enhance the flow of precompetitive technical information. Many companies share in the research performed by research consortia and government laboratories, and the spreading of information is often as beneficial as the creating of research breakthroughs. By spreading precompetitive knowledge widely, many companies acquire the basic technological information from which they can compete vigorously in product development. Fourth, the technology programs are linked with supportive economic and regulatory policies. The same Ministry with primary responsibility for promoting industrial technologies, MITI, can use its influence over trade, regulatory policy and industrial structure to create an environment conducive to the development of critical technologies. (For details, see the Council's occasional paper, *Japanese Technology Policy: What's the Secret?*, February 1991.)

European Community

The EC has a number of programs designed to attempt to help European industry, especially in electronics, where it is perceived to be trailing the United States and Japan. These include a number of programs under the jurisdiction of the Commission of the European Communities' "Framework," as well as the EUREKA program, which is outside the EC Framework.

Several programs within the EC Framework are designed to promote precompetitive research in key industrial technologies. ESPRIT (European Strategic Programme for Research and Development in Information Technology) funds microelectronics and computer technologies and has a 1988 to 1992 budget of about $2.2 billion. RACE (Research and Development in Advanced Communications in Europe) promotes telecommunications technology and has a 1987 to 1992 budget of about $750 million. BRIDGE (Biotechnology Research for Innovation, Development and Growth in Europe) focuses on biotechnology and has a 1990 to 1993 budget of about $140 million. BRITE/EURAM (Basic Research in Industrial Technologies for Europe and European Research on Advanced Materials) focuses on advanced materials and has a 1989 to 1992 budget of about $680 million. Each of these programs also gets money from industry.

EUREKA is a multicountry European R&D program, not directly affiliated with the EC, that is intended to build cross-border ties among research organizations and firms and to speed the commercialization of new products and processes.[5] It currently consists of about 300 projects in information technology, microelectronics, telecommunications, robotics and automation, lasers, new materials, biotechnology, transportation systems and environmental technologies. More than 1,000 European firms and research organizations are participating in the program, which receives 25 to 50 percent of its funding from public sources. Average annual expenditures exceed $1 billion.

These programs represent a clear attempt to identify and support strategic technologies that are critical to industry's competitiveness and to enhance collaboration among countries, industry, academia and public labs.

Another form of support for strategic technologies is demonstrated by Airbus Industrie. Direct financial support for development and production of commercial products and other financial subsidies by the French, German, British and Spanish governments have enabled Airbus to be competitive in the commercial aircraft industry, which, in turn, plays a key role as a driver of other technologies.[6]

In addition to these multinational programs, individual countries have programs to promote industrial competitiveness. Germany, for example, has an extensive system of research institutes (Fraunhofer Institutes) to promote excellence in manufacturing technologies. More than thirty of these institutes, which are funded by industry and government, focus on various aspects of manufacturing technology. The institutes are typically located next to, and work cooperatively with, universities that have complementary research centers. Industry participants provide equipment and research topics for the universities, which then train students and provide research results to the companies. Germany also has a series of activities in basic research, such as the Max Plank Institute and the Deutsche Forschungsgemeinschaft (DFG).

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[1] U.S. Department of Commerce, Technology Administration, *Emerging Technologies: A Survey of Technical and Economic Opportunities.* Washington, D.C., 1990.

[2] U.S. Department of Defense, *Critical Technologies Plan*, Washington, D.C., March 15, 1990.

[3] Japanese Ministry of International Trade and Industry, *Trends and Future Tasks in Industrial Technology* (Sangyo Gijutsu no Doko to Kadai), Tokyo, October 20, 1988.

[4] Commission of the European Communities, *First Report on the State of Science and Technology in Europe*, Brussels, 1988 (esp. p. 54-76).

[5] For a complete discussion, see Bozdogan, Kirkor, *The EUREKA Initiative in Europe: Implications for Technology Policy in the United States.* (Revised version of report prepared for the Carnegie Commission on Science, Technology and Government.) MIT Center for Technology, Policy, and Industrial Development. Cambridge, MA, March 5, 1990.

[6] Gellman Research Associates, *An Economic and Financial Review of Airbus Industrie* (Report prepared for the U.S. Department of Commerce, International Trade Administration), Jenkintown, PA, September 4, 1990.

CHAPTER IV

RECOMMENDATIONS

If the United States is to be competitive in the decades ahead, it must lead in the key technologies that are driving its industrial performance. The United States still has the finest research base in the world, but its ability to commercialize technology rapidly and to capitalize on market opportunities is being severely challenged. This report makes one overriding recommendation to remedy this situation. All other actions and programs stem from it.

IN ORDER TO CREATE QUALITY JOBS, GENERATE STRONG ECONOMIC GROWTH AND SAFEGUARD NATIONAL SECURITY, THE U.S. GOVERNMENT AND PRIVATE SECTOR SHOULD WORK TOGETHER TO DEVELOP COHERENT POLICIES TO ENSURE U.S. LEADERSHIP IN THE DEVELOPMENT, USE AND COMMERCIALIZATION OF TECHNOLOGY.

Current U.S. science and technology policy does not adequately address the commercial technology needs of American industry. New policy priorities are needed that focus on developing generic industrial technology and on diffusing it throughout the private sector. The recommendations that follow address the need to develop new national technology priorities.

Each sector has a responsibility. Government must work with the private sector to make the development and application of technology a new national priority. Industry must improve its ability to commercialize technology. And universities must make sure that their research and education programs adequately address the technology needs of industry. Working together, the public and private sectors can revitalize U.S. technological leadership and, in so doing, bolster the nation's industrial competitiveness and the prosperity of all American citizens.

GOVERNMENT RESPONSIBILITIES

The federal government has a responsibility to develop national technology policies that address issues related to U.S. industrial competitiveness. As discussed in Chapter I, it has taken several important steps in recent years, including

creating the Malcolm Baldrige Quality Award, strengthening the Office of Science and Technology Policy (OSTP), establishing the Technology Administration at the Department of Commerce and releasing its report, *U.S. Technology Policy.* All of these actions have contributed to more constructive interaction with the private sector. But these activities will have a limited impact on U.S. competitiveness without a priority federal commitment to facilitate the development and commercialization of technology. Although the government is a major funder of research and the U.S. research base is without peer, few federal R&D programs are relevant to the real needs of American industry.

Sustained effort is essential to the development and application of technology. In the short term, government regulations and procurement have a major impact on the application of existing technology. Over the long term, government investment in R&D and infrastructure is critical. Federal technology programs should recognize the importance of combining programs that promote the investment, development and use of technology in the short and long term.

Presidential leadership is also essential to success. The President is uniquely positioned to set national priorities, communicate them to the American public and directly involve key federal agencies in the effort to address them. Therefore, the full involvement and support of the White House is a key part of the effort to raise technology and competitiveness to a national priority.

The federal government can help facilitate U.S. technological leadership by taking the following four actions: 1) refocusing R&D, 2) facilitating investment and reviewing regulatory and legal barriers that impede commercialization, 3) improving the policymaking machinery, and 4) strengthening America's technology infrastructure. Policy recommendations in these areas are listed below.

1.

MAKE RESEARCH ON GENERIC INDUSTRIAL TECHNOLOGIES A NATIONAL R&D PRIORITY.

Current federal R&D spending has limited relevance to the technology needs of the U.S. private sector. Although defense-related R&D has helped U.S. industries in the past, these benefits are likely to decline in the future because the Defense Department is a technology leader in a diminishing number of industries. Moreover, programs that are directed specifically at industrial needs are extremely small. Other nations already spend more on nondefense R&D as a percent of GDP than the United States and are steadily increasing these levels. The United States should increase support for R&D and focus more resources on nondefense R&D that is commercially relevant. In order to promote more commercially relevant generic technologies as one of its priority R&D missions, the federal government should implement the following proposals:

■ *Establish a five-year implementation plan to increase dramatically the percentage of federal R&D expenditures for critical generic technologies.* The President should work with industry, the OSTP and relevant government agencies to devise a plan to increase significantly the amount of federal R&D that is focused on critical generic technologies. The President should announce this plan as part of his FY1993 budget.

■ *If federal budget pressures do not permit additional spending for generic industrial technology programs, then other federal technology programs should be redirected or phased in more slowly to free up the necessary resources.* In an era of limited resources for science and technology, the United States must choose its priorities carefully. The United States is spending a lot of resources on national prestige technology projects that make little contribution to U.S. economic growth

and competitiveness. Comparable spending on generic industrial technology would not only have a major impact on America's international prestige, but also its standard of living, national security and international influence. In allocating resources to its science and technology programs, the government should consider the magnitude of the potential benefit to U.S. competitiveness.

■ ***Strengthen the OSTP and fully support its efforts to work closely with industry to develop, on an interagency basis, strategies for leadership in key generic technologies.*** Working with the private sector and other government technology agencies, the OSTP has developed a list of critical technologies. The Council on Competitiveness has participated in the OSTP project, endorses its effort to identify key generic technologies and looks forward to continuing work with this office on critical technologies in the future. Having compiled its list of key technologies, the OSTP — working jointly with the private sector — should develop strategies for U.S. leadership in each of them. The OSTP currently has a small budget, with staff mostly on loan from other agencies. It should be expanded so that it has adequate resources to develop programs and keep in close touch with industry. The OSTP's new Critical Technologies Institute should help in the effort to develop strategies for technology leadership. This Institute should be funded for three years to give time to determine whether it can contribute to strategies for U.S. leadership in critical generic technologies. At the end of three years, it should be reevaluated to see if it has been effective.

■ ***Provide adequate funding for the National Institute of Standards and Technology (NIST) Advanced Technology Program and its Manufacturing Technology Transfer Centers to give them a chance to succeed, and establish benchmarks to make sure that industry is directly involved.*** Although the R&D budgets of most federal agencies have grown substantially over the past decade, NIST's budget has been essentially flat. The NIST budget should be increased so that it is adequate to contribute to U.S. leadership in generic technologies. NIST's Advanced Technology Program already has received start-up funds ($9 million in FY1990 and $36 million in FY1991). The original legislation for this program envisioned a budget between $100 and $250 million within four years of its creation. This level appears adequate, but the program should be carefully reviewed to make sure that it has a direct payoff for American industry. The current NIST plan is to increase the number of Manufacturing Technology Transfer Centers from 3 to 12 by 1995. These NIST programs focus primarily on small and mid-sized companies where increases in productivity and performance can have a major impact on U.S. competitiveness. NIST should coordinate its work on key technologies closely with the Defense Advanced Research Projects Agency (DARPA), which has extensive management experience in this area, and with the national labs.

■ ***Increase the focus of DARPA on manufacturing and dual-use technologies.*** DARPA has a proven track record of managing large, high-risk defense R&D programs. In the future, it should work closely with industry to play a more significant role in the development of generic industrial technologies, many of which overlap with defense technologies. Of the 23 key technologies DOD identified in its 1989 *Critical Technologies Plan*, 16 overlap with the key emerging technologies identified by the Department of Commerce. DARPA's programs in dual-use technologies should be coordinated with NIST.

■ ***Strengthen research at the National Institutes of Health (NIH) and enhance private-sector involvement in its programs.*** Technology development depends on a whole spectrum of activities,

from basic research to highly applied R&D. NIH basic research programs provide an essential foundation for many U.S. technology-intensive industries and should be kept strong. In the 1950s, NIH was one of the most prestigious government labs in the United States and perhaps the world. The quality of NIH research needs to be restored to this level.

■ *Enhance National Science Foundation (NSF) support for individual investigators and centers.* In its 1988 technology report, *Picking Up the Pace*, the Council on Competitiveness called for a doubling of the NSF budget over five years, a goal that President Bush subsequently endorsed. Although progress has been made, NSF budget increases have fallen short of this goal, and funding should be increased to meet it. The NSF makes a vital contribution to the nation's scientific base in its education programs and grants to individual investigators, and its programs should be strengthened. NSF Engineering Research Centers (ERCs), although hampered by a lack of funds, have received a positive evaluation from the National Academy of Engineering (NAE). The Council endorses the NAE finding that a renewed effort be made to achieve the original funding targets for the ERC program, and that, if funding constraints continue, priority be given to growing existing ERCs to their original award sizes rather than establishing new ones.

■ *Implement decisions to make sure that the federal laboratories' contribution to national technology needs is commensurate with the national investment in them.* Although the nation spends approximately $20 billion on the federal labs, their current culture and direction do not adequately support technology development that strengthens national economic performance. Except for the life sciences, the labs currently have little impact on the leading technologies driving industrial competitiveness — despite the Technology Transfer Act of 1986 and Executive Order 12591, which sought to increase technology flow from the labs to private firms. Some of the labs have valid national missions, but others have achieved their missions or have seen their mission requirements change. Although the Council has not studied the labs in depth, much of U.S. industry is convinced from first-hand experience that the labs are not closely integrated with the private sector and therefore doubts that sustained investments in them will result in a significant payoff for generic industrial technology. Positive reforms would include the following:

– Close and consolidate obsolete federal laboratories and scale back their funding in favor of university research.

– Make sure that industry is directly involved in the conception, design and management of any federal lab R&D programs devoted to generic technology before these programs are launched.

– Develop benchmarks to gauge the degree of industrial involvement in the labs' research programs, the industrial relevance of their R&D in the near term, and the potential for applications from their work in generic technologies over the long term.

– Insist on accountability from the federal labs in meeting goals based on these benchmarks.

– Reallocate resources at NASA labs to emphasize basic and applied research and technology validation of technical disciplines that are important to commercial aircraft.

2.

CREATE A U.S. ECONOMIC CLIMATE MORE CONDUCIVE TO MANUFACTURING, INNOVATION AND INVESTMENT IN TECHNOLOGY.

It is important that federal R&D regulatory and economic policies all point in the same direction. Unfortunately, private-sector commercialization efforts are all too often hampered by

inadequate incentives and confusing, often contradictory, economic signals. Specific proposals for making the U.S. economic climate more conducive to manufacturing, innovation and investment in technology include the following:

■ *Review the impact of government policies on the time-horizons of American management.* American managers do not operate in a vacuum. They are profoundly influenced by the overall economic environment. The U.S. Treasury Department already has undertaken some discrete projects that analyze how the broader economic environment affects corporate time-horizons. Treasury should expand these efforts to include a thorough assessment of how federal laws, economic policies and guidelines affect the time-horizons of U.S. managers. The results of the study should be widely publicized so that they can be fully discussed by Congress, the relevant regulatory agencies and the private sector. The Council on Competitiveness also has a major project under way with the Harvard Business School to examine the extent of the short-term focus of American business. The Council will be releasing preliminary policy recommendations in this area in late 1991.

■ *Make the cost of capital for the development of priority technologies competitive with that of America's major competitors.* The high cost of capital is a major disincentive for investment in technology development. In addition to macroeconomic actions that reduce the budget deficit and increase national savings, three critical priorities stand out:

– Accelerate depreciation schedules and capital cost-recovery programs for manufacturing equipment and facilities so that they are competitive internationally. Shorter depreciation schedules would create a strong incentive for private-sector investment in state-of-the-art equipment that would enhance U.S. productivity.

– Make the R&D tax credit permanent and amend it to include manufacturing engineering and process R&D. The current R&D tax credit is a step in the right direction and should be made permanent, but its benefits are limited primarily to small and rapidly growing companies. America also needs broad incentives that promote major U.S. enterprises to significantly increase their investment in R&D. The government should build on the existing tax credit to stimulate private-sector R&D more broadly.

– Place a permanent moratorium on Treasury Regulation 1.861-8, which prevents U.S. companies with excess foreign tax credits on their overseas operations from deducting for U.S. tax purposes a portion of their domestic R&D expenditures. This regulation increases the effective rate of U.S. taxation of R&D and creates a disincentive for companies to conduct R&D in the United States.

■ *Have the Justice Department work with industry groups and professional societies to remove barriers that prevent industry-wide cooperation on generic technology issues.* Supplier networks and cooperative technology ventures among companies, trade associations, professional societies and R&D consortia can make a vital contribution to diffusing knowledge about leading-edge technology and best commercialization practices. Current antitrust laws — or the perception of them — may sometimes discourage socially beneficial technological cooperation among these groups. The Justice Department should work with industry groups to remove barriers to technological cooperation. One promising technique is to allow individual firms to enter into joint ventures that enable them to share the substantial risks and costs of investment in strategic technologies.

■ *Orient federal laws and regulations to the reality of the international marketplace and strengthen the performance of key agencies.*

Although the Council on Competitiveness recognizes that regulations are established for a variety of purposes, it believes that one of their explicit objectives should be to stimulate innovation in technologies that will boost U.S. competitiveness. To that end, the Council recommends the following:

– Strengthen the effectiveness of the U.S. private-public system for establishing U.S. standards and gaining their acceptance in world standards bodies. The U.S. representative in the International Standards Organization (ISO), which is the worldwide standards setting group, is the American National Standards Institute (ANSI) — a private organization working closely with U.S. industry. ANSI is less effective than it once was because it now confronts other countries' national standards strategies to promote their native firms' interests. The ANSI process must receive more attention to ensure that world standards are compatible with the commercial interests of U.S. firms.

– Improve the quality and speed of oversight of such agencies as the Food and Drug Administration, the Federal Communications Commission, the Environmental Protection Agency, the Justice Department, the Federal Trade Commission, the U.S. Patent and Trademark Office, and the Federal Aviation Administration.

– Revise product liability laws in such a way as to encourage innovation while protecting consumers. The United States should adopt more uniform product liability standards based on the right to fair compensation for actual damages, liability based on responsibility for harm and encouragement of alternatives to costly litigation.

3.

COMMUNICATE THE PRIORITY OF TECHNOLOGY AND COMPETITIVENESS TO THE AMERICAN PUBLIC AND INVOLVE KEY POLICYMAKING BODIES MORE CLOSELY IN THE ISSUE.

The United States possesses an extraordinary amount of technological talent, and there is a growing consensus that it must be better harnessed to improve U.S. industrial competitiveness. There is no substitute for Presidential leadership. The President can set national priorities, establish goals, create new programs and missions and instruct federal agencies to fulfill them. He should highlight the importance of technology and competitiveness in addresses to the American public and in his budget submissions, and direct key policy councils to focus on these issues. The Council recommends the following specific actions:

■ ***Highlight the priority of technology and competitiveness in the annual State of the Union address, annual budget submission and in other national forums.*** The President should consistently impress on the American public the importance of technological leadership for U.S. jobs, standard of living and national security. This message should become a standard theme of the President's public statements.

■ ***Expand the focus of the National Security Council (NSC) to include issues related to economic performance and technological strength.*** There is a pressing need to increase the level of Presidential attention to technology issues that have an impact on economic performance and national security. The NSC has the mandate, the resources and the stature to bring these issues within a common framework for Presidential decision making. It should view issues related to technology and economic security as one of its priority missions and expand its competence in this area accordingly.

■ ***Designate the Federal Coordinating Committee on Science, Engineering and Technology (FCCSET), through its Committee on Technology and Industry, to review and coordinate government programs on critical technologies.*** FCCSET's

Committee on Industry and Technology is already reviewing government-wide programs in materials and manufacturing in order to identify federal R&D strengths and match them with industrial needs. This review is a very positive step and should be expanded to include R&D programs in the 23 critical technology areas the Council has identified. Having taken an inventory of government R&D programs in these areas, FCCSET should help coordinate R&D activities across government agencies. The President should fully support these actions.

■ *Make competitiveness a priority focus of the President's Council of Advisers on Science and Technology (PCAST) and encourage it to highlight the importance of domestic technology issues, such as manufacturing, investment in R&D and the skills of the American work force.* PCAST brings together a unique group of leading experts in science and technology for regular consultations with the President and his closest group of advisers. It should devote a significant portion of its time and resources to issues related to technology and economic performance and increase the President's attention to these matters. Discussion of market-related developments that help clarify America's competitive position and investment needs in technology are especially important. PCAST should be given adequate staff and resources to be an effective voice in these discussions.

4.

DEVELOP POLICIES AND PROGRAMS TO ENSURE THAT AMERICA HAS A WORLD-CLASS TECHNOLOGY INFRASTRUCTURE.

In the past, government missions such as space exploration and national defense have served as a valuable market pull for emerging technologies. Today, they are increasingly losing relevance for commercial needs. In determining their infrastructure programs and procurement policies, the federal and state governments should make sure that they encourage the development, commercialization and use of new technologies.

■ *Strengthen investment in America's technology infrastructure and create a market pull for critical generic technologies.* The nation's technology infrastructure is critical to its international competitiveness. Technology infrastructure consists of physical assets, such as equipment, facilities and networks, and human capital, such as skilled scientists, engineers, managers and other personnel. Infrastructure programs traditionally have been a responsibility of the federal and state governments. From the mid-1950s to the mid-1980s, however, public investment in infrastructure has declined from 5.8 to 3.9 percent of GNP (1.9 to 1.5 percent when military spending, schools and highways are not included). Infrastructure programs spur investment in the generic technology, human capital, facilities and equipment that drive economic growth and productivity. The federal government should assess the nation's technology infrastructure needs, benchmark what foreign governments are doing and develop strategies, programs and implementation plans to make sure that the United States has a world-class technology infrastructure. For example, NASA's wind tunnels and simulators are critical to the competitiveness of the U.S. commercial aerospace industry and represent part of the nation's technology infrastructure that should be fully maintained. The Administration's 1989 report, *The Federal High Performance Computing Program*, and related Congressional legislation that supports interagency cooperation represent another important infrastructure program that deserves to be fully implemented. This initiative combines several essential aspects of a successful technology infrastructure program:

– Broad relevance for many different sectors of the U.S. economy.

– Close links with public- and private-sector efforts to develop relevant critical generic technologies.

– Support for education at all levels.

– Investment in related investments in university research, education, facilities and equipment.

– Measures that make it easy for industry to invest in, deploy and use the infrastructure to enhance its competitiveness.

■ *Make the federal government a discriminating customer of technology products.* Like industry, the U.S. government should benchmark the practices of foreign governments and private companies, and develop appropriate goals for improving government procurement policies and practices.

– Give the National Institute of Standards and Technology, working with industry in an open standards-setting process, the responsibility for adopting within the government dual military-industrial standards.

– Replace one-half of Defense Department mil-spec standards with dual military-industrial standards by 1995 and three-fourths by the year 2000.

– Encourage government contractors to qualify for the Malcolm Baldrige Quality Award.

Industry Responsibilities

The private sector has the primary responsibility for the commercialization process, and many of America's competitiveness problems stem from industry's failure to commercialize technology effectively. Inadequate cooperation between suppliers and customers, between businesses and universities and between industry and the federal labs compounds the problem. Unless American firms improve their ability to reach out and bring technology to market rapidly in the form of quality products, processes and services, U.S. competitiveness will continue to erode — no matter how ambitious or far-reaching government technology policy is. During the past decade, U.S. industry has made some impressive progress in responding to international competition, but it still has a long way to go. Private-sector recommendations are listed below.

1.

ESTABLISH MORE EFFECTIVE NETWORKS AMONG U.S. INDUSTRY GROUPS TO ACCELERATE THE DIFFUSION OF TECHNOLOGY, FACILITATE COMMERCIALIZATION AND PROMOTE LEADERSHIP IN CRITICAL GENERIC TECHNOLOGIES.

Trade associations, professional societies and R&D consortia should all play more substantial roles in promoting U.S. technological leadership. Although there is an understandable reluctance to share proprietary technology, these private-sector groups can, and must, do a better job of diffusing new ideas and sharing the cost and risk of developing technology. The Council on Competitiveness will take a leading responsibility to work with these groups to promote these networks. The Council will assess how trade associations and other groups in other countries work with their members to promote technological leadership, attempt to clarify government restrictions that discourage private-sector cooperation in the development of generic technology and, to the extent that it is able, serve as a clearinghouse for information about programs and management practices behind successful technology networks. Private-sector groups should focus on the following activities:

■ *Strengthen competence in technology issues.* Many private-sector groups, especially trade associations, tend to focus on broader tax, trade or regulatory issues and fail to devote adequate attention to their industry's technological performance. These groups should strengthen

their technical expertise, more systematically follow technology developments that affect their industry's competitiveness and work closely with their members to make sure that their technology needs are met.

■ *Clarify the antitrust restrictions that inhibit the establishment of technology networks.* Many groups are inhibited from pursuing issues related to generic technology because of a concern about violating U.S. antitrust law. These groups should clarify antitrust restrictions that affect their ability to share technical and market information about generic technologies. The Council will cooperate in this effort.

■ *Identify and disseminate information about key generic technologies and world-class commercialization practices.* Having strengthened their technical capabilities and clarified the legal restrictions governing their activities, private-sector groups should identify the generic technologies that are critical to their industry. They should keep their members current of new developments in these technologies and, to the extent that they are able, share information about world-class commercialization practices.

■ *Develop programs to promote U.S. leadership in critical generic technologies.* Private-sector groups should not limit their activities to information sharing. They should also develop programs to strengthen the technological competitiveness of their members. Examples might include cooperative R&D ventures, programs that focus on improving commercialization systems and efforts to strengthen manufacturing processes.

■ *Promote supplier networks that cooperate to set standards and share information in critical technologies.* Supplier networks contribute to the level and quality of technology that individual companies can deliver. By improving suppliers' ability to meet users' technology needs, they can significantly enhance an industry's competitiveness. Key concerns are the need to set standards and the need to share information about key generic technologies in ways that enhance U.S. industrial competitiveness.

2.

SET A GOAL FOR U.S. FIRMS TO MATCH AND SURPASS THE BEST COMMERCIALIZATION PRACTICES OF THEIR COMPETITORS, DOMESTIC OR FOREIGN.

U.S. companies should understand and improve upon the successful commercialization practices of their competitors. To achieve this goal, U.S. firms should benchmark their competitors. They should set appropriate goals and allocate the necessary resources. They should motivate, train and empower their employees to take responsibility for achieving these goals. And they should develop the external relationships necessary to accelerate the commercialization process. The Council on Competitiveness will encourage industry to improve its ability to commercialize technology. Action in the following seven areas is especially important:

■ *Match the President's goal to increase dramatically the R&D allocated to critical technologies.* Industry should work with the government to help establish a five-year plan to increase significantly the percent of federal R&D that is focused on critical technologies. Industry should also accept the responsibility to increase significantly the level of its R&D and should develop a program to match the President's goal.

■ *Institute total quality management and continuous improvement.* The Malcolm Baldrige Quality Award has had a tremendous impact on U.S. industry and has been instrumental in making quality a national goal. Despite the progress some companies have made, however, American industry needs to do more. U.S.

manufacturing and service companies, their suppliers and government contractors should all make quality a fundamental priority and implement continuous improvement programs.

■ *Strengthen manufacturing process engineering.* Inadequate attention to process engineering is a major reason for American industry's competitiveness problems. Many firms have emphasized finance, marketing and new product development at the expense of manufacturing processes. U.S. companies should train the personnel and make the investments that are necessary to improve their manufacturing processes.

■ *Accelerate time-to-market to competitive levels.* Japanese companies have effectively used concurrent engineering and parallel product development — in which engineers focus on the development of second- and third-generation products along with the initial version — as a means of accelerating the time it takes to get new products to market. U.S. companies should learn from the Japanese experience and reduce the time necessary to commercialize new technology.

■ *Improve the ability to share risks and spread costs for developing technology across a broad base.* As the cost of developing new technology has risen and the speed of product cycles has increased, it has become more difficult for individual firms — no matter how large — to develop the technology they need on their own. Germany and, especially, Japan have industrial structures that help companies share the risks and costs of technology development. U.S. firms should work together and with universities and federal laboratories to reduce the costs and risks of developing technology.

■ *Continuously upgrade the skills of the work force.* A skilled work force is an essential asset in the effort to improve quality, strengthen process engineering and reduce time-to-market. U.S. firms should systematically train members of their work force to make sure that they have the necessary skills.

■ *Encourage corporate executives and general managers to give strategic factors equal weight with financial projections in technology-based businesses.* Employees at all levels of industry should be involved in the effort to improve technological competitiveness. It is especially important, however, that senior managers view strategic technology issues as one of their top priorities. Otherwise the importance of these issues will not be adequately communicated to the rest of the enterprise. This focus is closely related to the effort to improve the management systems that support long-term planning and investment.

3.
INCREASE DIRECT INDUSTRY WORKING RELATIONSHIPS WITH UNIVERSITIES IN KEY TECHNOLOGIES.

America's research universities are underutilized by American industry. Industry cannot just send grants to universities or participate in visiting committees that meet once a year and expect to reap sizeable technological rewards. Industry should establish direct one-on-one relationships between industrial engineers and university research engineers and encourage personnel exchanges, consulting arrangements and cooperative ventures. Close involvement in key university research programs can provide industry with early access to new ideas that can provide an edge in world markets.

University Responsibilities

America's research universities are one of the nation's great technological assets, and their programs should be strengthened. They have a key role to play in promoting U.S. leadership in generic industrial technologies. Although the

Council has a keen interest in the effort to improve the U.S. educational system, the focus of this project was limited to how America's research universities can work with industry to strengthen U.S. technological competitiveness. It is important to note, however, that universities' primary responsibility is to their students — undergraduate and graduate. In the long run, the quality of the education they provide will be a critical determinant in how competitive the future employers of their graduates will be.

1.

DEVELOP CLOSE TIES WITH U.S. INDUSTRY AND MAKE EFFORTS TO ENSURE THAT IMPORTANT TECHNOLOGY DEVELOPMENTS ARE COMMUNICATED TO POTENTIAL U.S. USERS ON A PRIORITY, EXPEDITED BASIS.

More and more universities are reaching out to industry for resources and ideas. This trend should be encouraged. Because much university research is funded by U.S. industry and government, American universities should attempt to provide potential U.S. users early access to their work. A preferred time-advantage can give industries a competitive edge and provide them with an incentive to work more closely with university research programs.

2.

MAKE EFFORTS, IN COOPERATION WITH EMPLOYEES, TO ENSURE THAT EDUCATIONAL PROGRAMS IN ENGINEERING AND MANAGEMENT REFLECT THE REAL NEEDS OF THE MANUFACTURING AND SERVICE SECTORS.

In pursuit of a theoretical knowledge of issues related to technology and manufacturing, many universities have lost sight of the need to teach industrially relevant technology skills to students. Universities should promote understanding and competence in the process by which a product is carried from conception through design and manufacture to market. Many companies participate in programs that involve seasoned managers and researchers in university teaching programs. These programs help make students aware of the real needs of industry. They should be encouraged and widely emulated.

- ***Include in the undergraduate curriculum a heavier focus on design and understanding of manufacturing systems.***
- ***Make ample use of adjunct instructors who are active in industry and familiar with modern industry practices.***
- ***Encourage students to spend time in industry.***
- ***Improve undergraduate laboratories.***

3.

KEEP BASIC SCIENCE AND ENGINEERING PROGRAMS STRONG AND STRENGTHEN UNIVERSITY RESEARCH CAPABILITIES SO THAT THEY CAN ADEQUATELY ADDRESS FUNDAMENTAL, LONG-TERM RESEARCH THAT IS RELEVANT TO INDUSTRY.

America's research universities provide the nation with an unparalleled capability in basic research. This capability has made an enormous contribution to America's technological performance and should be strengthened. Industry, government and universities need to work together to assure that university basic science and engineering programs are maintained at a high level. Moreover, they should work to see that academic research adequately supports the technical understanding that contributes to generic industrial technology.

APPENDIX I:

LESSONS FROM THE NINE SECTORS

The nine sectors that the Council studied represent a broad cross section of U.S. industries. They include industries with substantial trade surpluses and deficits, and they represent manufacturing, service and information industries. Together, these nine sectors account for about 12 million jobs and over $1 trillion in sales. Their R&D spending ranges from less than 0.1 to 14 percent of sales. They include industries dominated by defense and civilian markets, and industries with rapid and slow product cycles. This diversity provided rich insights into the strengths and weaknesses of technology development in U.S. industry.

The analysis of each sector focused on:

- Its competitive position.
- The technologies that are important to it.
- How it develops and uses technology.
- Its performance in developing technology.
- The factors supporting and inhibiting its technology development.

The following are summaries and key lessons of each sector.[1]

1. AEROSPACE

AEROSPACE	
World Market:	$200 billion (est.)
U.S. Shipments:	$120 billion (1990)
Employment:	814,000 (1990)
Exports:	$38.2 billion (1990)
Imports:	$10.2 billion (1990)
R&D as % of Sales:	4.1% (1989)

The U.S. aerospace industry has been the world leader since World War II, but its lead is increasingly being challenged by foreign airframe and component producers.

There are three main sectors of the aerospace industry: civilian aircraft (16.7 percent of total aerospace sales in 1988), military aircraft and missiles (45.5 percent of sales) and space (21 percent of sales). Sales of related products and services account for the other 17 percent of sales.

The aerospace industry is composed of a few large integrated producers that draw from an extensive, varied and increasingly international supplier base. The U.S. component base underlying the aerospace industry has become weaker as a greater percentage of aircraft components are sourced internationally.

The aerospace industry is a major part of the U.S. economy and contributes significantly to U.S. trade performance. It is also vital to U.S. national security and is the user and driver of many advanced product and process technologies. These include advanced materials, a wide variety of electronics and information technologies, and propulsion technologies.

There has been an increasing divergence between defense and civil aerospace needs, resulting in a major decrease of technology transfers from military to civilian uses. Defense emphasizes high performance, whereas civilian aerospace emphasizes efficiency and safety. Government procurement regulations also serve to separate the markets by encouraging companies to keep their government and commercial businesses separate.

The current success of the U.S. civil aviation industry owes much to a strong working relationship between aircraft manufacturers, operators and the government. All three sectors have played a leading role in setting worldwide technological, operational and safety standards, and each sector is essential to the future competitiveness of the U.S. civil aviation industry. However, indications are that the government sector may not be performing to past high standards, therefore threatening the future vitality of the whole industry.

Government support has proven to be essential to foreign firms' emergence as competitors in commercial aerospace. Since the inception of Airbus Industrie, the governments of France, the United Kingdom, Germany and, to a lesser degree, Spain have provided in excess of $20 billion in direct support, enabling Airbus to develop a full family of commercial aircraft that compete head-to-head with U.S. manufacturers.

Commercial aircraft is a high-risk field. It takes several billion dollars and more than a decade to bring a new commercial aircraft to market. Joint ventures are becoming more prevalent in the industry, in part to share risks. The increasing internationalization of the industry is also due to the enormous costs involved in developing new engine and airframe technologies. The deregulated, price-competitive U.S. airline industry is less willing to finance and exert a demand pull for advanced technologies than in the past.

Lessons

- Military R&D is providing fewer spillover benefits to commercial sectors of industry. This trend began before recent defense budget reductions and is likely to be exacerbated by projected cuts. Civilian technology, on the other hand, is becoming more important to defense needs, especially at a component level.
- First-rate regulatory agencies are often key to an industry's competitiveness. The Federal Aviation Administration's role as the world's preeminent setter of aviation safety standards needs to be revitalized to counterbalance the emerging dominance of the European Community as a regulatory body in the civil aviation sector. Otherwise, the Europeans will eventually set world aviation standards, which will hurt the future competitiveness of the U.S. civil aviation industry.
- The U.S. relative strength in several industries is in systems-technology integration — the ability to bring components together to form complex systems. Industries that rely on systems-integration skills, however, may be undermined by weakness in component technologies.
- The aerospace industry has been weak at the technology validation stage of the R&D process due to past policies that encouraged a clear separation of the government and industry roles. This stage involves ensuring the performance and reliability of technologies before they are incorporated into more complex systems. Cooperative government-industry relationships are key at this stage. NASA's aeronautical policy should be amended to include the technology validation of research results, and NASA should maintain and expand the required research infrastructure, such as wind tunnels and simulators.
- When industries are knowledge- and capital-intensive, have high barriers to entry and are vital to national prestige and defense, governments will support their development, as in the case of aerospace. Government policies should be tailored to address this reality.

2. Chemical and Allied Products

CHEMICAL AND ALLIED PRODUCTS	
World Market:	$960 billion (1989)[2]
U.S. Shipments:	$292 billion (1990)
Employment:	832,000 (1988)
Exports:	$36.5 billion (1990)
Imports:	$20.7 billion (1990)
R&D as % of Sales:	3.8% (1989)

The U.S. chemical industry produces thousands of products, from bulk chemicals to high-technology products such as electronic materials. It operates

worldwide and has maintained a trade surplus. This surplus declined in the early 1980s but recovered after the industry undertook a difficult restructuring that continues today.

About half of the chemical industry's output goes to other manufacturing industries in the form of technologies such as chemicals, composites, ceramics, plastics, polymers, electronic materials, optoelectronic materials, biomaterials and biotechnology-produced products. These technologies make possible new products and processes in other industries. The health of those industries, in turn, determines the market for the chemical industry.

The industry is both R&D- and capital-intensive. R&D expenditures in 1989 were equal to 3.8 percent of sales (excluding pharmaceuticals).

The chemical industry relies on basic research in the chemical, biological and physical sciences to develop new products. It also depends on scientific instruments, computers and databases. Furthermore, it relies on a wide variety of materials processing technologies and sensors, and controls.

The industry is highly regulated. Environmental, health and safety laws control the environmental release, disposal, transportation, workplace exposure and use of various chemical products. Environmental technologies, including redesigned processes to reduce waste and meet environmental standards, recycling, and environmentally benign products will be critical to the industry in the coming decades.

Lessons

- In rebounding from its problems of the early 1980s, the chemical industry showed that capital-intensive, high-volume U.S. industries can still be competitive. Its success is linked to several factors. Because process and product technology are inseparable in the chemical industry, the industry never ignored process engineering. Because the industry has long been exposed to international competition, it faced its problems early on. And because it had a long history of technically trained management and a corporate culture of innovation, the industry never stagnated.
- Even industries that successfully meet international challenges cannot relax. There is increasing international competition in the high-technology segments of the chemical industry, with companies and government organizations in many countries emphasizing the development of advanced materials. U.S. industry will need to redouble its commitment to innovation to remain competitive.
- Environmental regulations increase costs and may force weaker companies out of business but, contrary to popular perception, do not necessarily undermine U.S. competitiveness. Environmental standards are rising around the world, and often companies that are forced to meet stiffer standards gain a technological lead over companies in countries with more lax standards. Requirements to reduce waste can also result in more efficient processes that ultimately save money.
- The demand for advanced products is critical to the success of industries. The demand by other industries and the federal government for state-of-the-art materials strongly influences the chemical industry's ability to be a world leader in those technologies.
- Science-based industries such as the chemical industry benefit from strong basic research and trained researchers from universities, and strong intellectual property protection.
- Chemical engineering is unique among academic disciplines in that it combines basic knowledge and theory with issues related to manufacturing and production. By thoroughly educating chemical engineers in these areas, academic training has made a major contribution to the competitiveness of the industry.

3. Computers and Software

COMPUTERS AND SOFTWARE	
World Market:	$194 billion (1990)
U.S. Shipments:	$100 billion (1990)
Employment:	587,000 (1989)[3]
Exports:	$24.7 billion (1990)[4]
Imports:	$25.2 billion (1990)
R&D as % of Sales:	9.0% (1989)[5]

Advances in computers and software have driven major changes in virtually every other sector of the U.S. economy and are also critical to the national defense.

U.S. computer systems firms are still the dominant producers in world equipment and software

markets, but U.S. leadership is under assault. The U.S. balance of trade in computers has deteriorated substantially in the last decade. The world market share of U.S. companies fell from 81 percent in 1983 to 61 percent in 1989, and the products of U.S. companies included a greater proportion of imported components.

The computer industry depends on a diverse set of component industries, including the computer equipment, software, tool and test, semiconductor manufacturing, and peripherals and components industries. The U.S. strength is concentrated in knowledge-intensive areas such as computer architecture, systems integration and software.

The United States leads the world in highly creative technologies such as software, networks and communications, and computer architecture. These technologies have been targeted by offshore competitors who are undertaking extensive R&D efforts to close the gaps.

The United States currently lags the rest of the world in many of the components that the computer and software industry depends upon, including microelectronics, integrated circuit fabrication equipment and facilities, electronic packaging and manufacturing technologies. The United States also lags in printers and optical storage.

Continued success in the knowledge-intensive parts of the industry depends on skilled and creative personnel, effective intellectual property protection and U.S. leadership in standards.

Lessons

- The knowledge-intensive segments of the industry remain strong because those segments tend to be less capital-intensive and less vulnerable to high capital costs and because they benefit from the excellence of U.S. universities. Skilled people are the most important success factor for these segments of the industry.
- The industry's strength in systems integration and software is vulnerable to weakness in the underlying industries that provide components and equipment.
- The factors that influence the success of the electronic components industry also influence the success of the computer industry. These include capital costs, manufacturing capability, quality management and access to large volume markets.
- Defense R&D funding and procurement traditionally provided major benefits to the computer industry, but these benefits have significantly decreased in recent years.

4. Construction

CONSTRUCTION	
U.S. Market:	$445 billion (1990)
Employment:	6,700,000 (1990)
Foreign Contracts by U.S. Firms:	$38.3 billion (1989)
U.S. Contracts to Foreign Firms:	$15.5 billion (1989)
R&D as % of Sales:	0.02% (est.)

Construction is a huge and fragmented industry. It is usually considered to consist of the firms providing design and construction services, but construction material and equipment suppliers are also closely connected to the industry.

Construction is different from manufacturing in that the end products — constructed facilities — are generally not shipped. International trade in the industry is primarily in design and construction management services and in construction-related materials and equipment.

The international construction market is different from the domestic market. The international market is characterized by large and technically complex projects and is dominated by large companies. The domestic market is characterized by a greater number of smaller companies and less technical projects; to a large extent, it is isolated from international competition.

The U.S. construction industry is competitive in the international construction services market, but its substantial post-World War II lead declined significantly in the past decade. In 1980, U.S. construction firms captured 45 percent of all international construction contracts; by 1989 they had captured only 28 percent.

The construction industry is a low-R&D, low-productivity growth industry. U.S. construction contractors spend only about 0.02 percent of sales on R&D. The construction industry primarily relies on other industries for new technologies. Most construction technology is developed by materials and equipment manufacturers, universities and, to a limited extent, government laboratories, such as the National Institute

of Standards and Technology's Building and Fire Research Laboratory. The U.S. construction industry still has a strong position in many construction technologies, but its lead has eroded and it now lags behind in many areas of technology. The industry is beginning to recognize some of these problems and has begun to develop closer links with university research. More emphasis on research and testing of new construction technologies by government laboratories could also aid the industry.

A key problem is getting technology into the industry. Testing is expensive and time-consuming (partly because of the long life required of construction technologies), and problems are expensive to fix. Product liability lawsuits act as a means of protecting people from poor quality but also discourage taking risks in the employment of new technology. Much of the U.S. weakness is not so much in developing the new technologies as in adapting them to the construction industry and then proving their reliability and durability.

Many of the key technologies are computer and software technologies used in the design and engineering of buildings and in managing the construction process. These include computer-aided design and engineering, databases, expert or knowledge-based software, simulation and planning/scheduling/inventory management systems. The industry also depends on advanced construction equipment, sensors and a variety of materials such as concretes, composites, steels, plastics, ceramics, textiles and glass.

Lessons

- Strong, cost-based competition encourages firms to aggressively seek ways to reduce costs and improve efficiency but can also lead to low profit margins and an inability to fund R&D. In Japan, the construction industry competes less on price and has greater resources to fund R&D but may have less incentive to use cost-saving new technologies. Methods need to be found to encourage more U.S. construction R&D.
- The construction industry relies on other industries for technology, and its health depends on these other industries. If other U.S. industries lose their leadership in technology, the construction industry is likely to follow.
- In industries that integrate components and subsystems from many other industries, validating the reliability of new technologies is a major bottleneck. As a result, the U.S. construction industry is a major user of new technologies that it can take off the shelf but is weak in using new technologies that require experimentation and testing.
- Government procurement procedures — which typically award projects based on low first costs rather than long-term costs or quality and typically require separate bids for the design and construction stages of projects — provide a disincentive for innovation in the industry.

5. Drugs and Pharmaceuticals

DRUGS AND PHARMACEUTICALS	
World Market:	$150 billion (1989)
U.S. Shipments:	$54.9 billion (1990)
Employment:	178,000 (1990)
Exports:	$5.3 billion (1990)
Imports:	$4.2 billion (1990)
R&D as % of Sales:	12.0% (1990)[6]

The U.S. pharmaceutical industry has been very successful. It is the largest in the world, is highly profitable and is a major force in the international market. Sales to U.S. consumers constituted 20 percent of the world total in 1988, while sales by U.S. firms were approximately 30 percent of the world total. Although the U.S. pharmaceutical industry has historically maintained a trade surplus, this has declined and almost disappeared as the market has become increasingly global.

The two segments of the prescription pharmaceutical industry operate with notably different competitive strategies. Research-based companies, accounting for 70 percent of total sales, specialize in name-brand products. Success depends on having a sufficient stream of new drugs that offer advantages over other drugs on the market; thus, the pharmaceutical industry has the highest ratio of R&D funding to sales of any major U.S. industry. On the other hand, generic companies, selling unbranded products after the

expiration of the pioneer products' patent, emphasize price.

The U.S. Food and Drug Administration (FDA) regulatory-approval procedures govern the drug-development process. Before a new drug can be marketed, the drug's sponsor must demonstrate the drug's safety and efficacy and assure the maintenance of quality throughout the production process.

Getting a new drug through this process and to market is risky, expensive and time-consuming. On average, for each new drug approved by the FDA, drug companies screen 4,000 to 10,000 chemicals and test 5 to 10 drugs in human clinical trials. For products introduced in the early 1980s, it took an average of 12 years and more than $200 million (including indirect costs) to bring a new drug to market.

Competition to develop the best product within a therapeutic area can be fierce. The development process is not only long but also unpredictable. Even clinically successful outcomes may not be financially rewarding. Only a small proportion of new drugs reward the sellers with large profits. Achieving high profits on a few products is essential to funding the research that may lead to new therapies, especially since most private pharmaceutical R&D is financed out of the company's retained earnings.

Companies have a short period to recapture their investment in the drug, relative to the 12-year average time necessary to discover and develop a new drug. Of an official 17-year patent life, half may pass before the FDA can complete its review and approval process. Moreover, this short recovery period has in recent years become even shorter as generic drugs have been used more quickly after the pioneer product's patent expires. The reduction in a new drug's lifetime earnings puts a concomitant pressure on funds available for R&D.

The high cost and risk of drug development, plus the need to market drugs globally to maximize their earnings, are encouraging worldwide alliances and the consolidation of companies to finance the development and worldwide marketing of drugs.

The pharmaceutical industry is science-based and relies on advances in basic research, as well as more incremental advances, for drug discovery and development. Research in a wide range of biological, biomedical and chemical disciplines is vital to understanding how to create chemicals that will affect specific biological processes. Modern biotechnology (including recombinant DNA, cell fusion and bioprocessing techniques) has become an integral part of this research base, as well as a means of producing drugs. The industry also relies on a number of technologies produced by other industries, such as scientific instruments, and computers and software for molecular analysis, modeling and graphics. Databases and networks to store, manage and access research and clinical trial results are also critical.

Lessons

- In science-based industries, federal support of basic research and training of scientists — the traditional federal role — is essential. Strong federal support for biomedical research, especially the $7 billion annual funding of National Institutes of Health (NIH) research, has been a major competitive advantage for the industry. Even so, critics warn that America's funding commitment has not kept pace with the growing complexity and cost of research at the scientific frontier. There is also a critical concern that the pool of talent is eroding, due to weaknesses in U.S. science education.
- For the pharmaceutical industry, redirection of government and university research toward applied research is not desirable. Strong support of basic research is essential, and researchers will be attracted to biomedical research only if provided with both opportunities and an array of intellectual challenges.
- To allow industry to recapture the investment in R&D, strong intellectual property protection and avoidance of intrusive drug-pricing mechanisms are important. Foreign protection of intellectual property rights, currently weaker than in the United States, must be strengthened.
- A strong and technically competent regulatory agency is a competitive plus in the international arena. The FDA, criticized by some as being too slow at approving drugs, has a generally good record for maintaining public confidence in the safety and efficacy of drugs. To support the industry's competitiveness, greater resources are needed to maintain an adequate FDA technical staff that can keep up with changes in science and technology and reduce the backlog of drug applications.

6. Electronic Components and Equipment

ELECTRONIC COMPONENTS AND EQUIPMENT	
World Market:	$150 billion (est.)
U.S. Shipments:	$62.6 billion (1990)
Employment:	520,000 (1990)
Exports:	$13.4 billion (1989)
Imports:	$17.7 billion (1989)
R&D as % of Sales:	6.5% (1989) [7]

The electronics components industry has long been an area of strength in the U.S. economy and a showcase of U.S. entrepreneurial prowess. The U.S. industry has invented most of the basic technologies and has led in the formation of new electronics companies. Although the U.S. electronics components industry retains leadership in some areas, such as microprocessors, it has increasingly lost control of other markets, such as memory chips.

This industry is of major importance to all modern industrial economies, and its impact extends to virtually all sectors — ranging from aerospace to computers. It is a high-growth industry and is targeted by many nations as strategic for defense and commercial reasons.

The industry is characterized by high developmental and capital costs, declining marginal costs of production, rapid product cycles incorporating incremental improvements and pronounced business cycles.

The industry structure is that of a food chain, extending from raw materials and production equipment to products and integrated systems. The industries that make up this chain each require access to capital, world-class suppliers and leading customers. The U.S. electronics industry structure, unlike that of competing countries, consists mainly of autonomous firms (not related to upstream or downstream companies). Companies in this structure are less able to ensure access to suppliers and customers and tend to be less able to bear financial risks. High fixed-capital costs make autonomous components, materials and production equipment firms vulnerable to unpredictable market fluctuations. Materials and production equipment firms have been especially weak. Small high-technology, electronics-related firms have been attractive targets for foreign acquisition.

The rapidly changing nature of the industry demands a highly skilled and adaptable work force, and changes in business time horizons and management techniques.

A number of technologies are critical to the electronic components industries, including computer-aided design and engineering tools, state-of-the-art process equipment and process controls, and electronic materials.

Lessons

- Even high-technology U.S. industries are vulnerable to focused foreign competition.
- A failure to invest in one generation of electronic component technology may provide the opportunity for foreign competitors to enter and capture the markets of successive, increasingly lucrative generations of technology.
- An industry's ability to cross subsidize across businesses can be an important factor in its overall strength. End-product manufacturers require healthy equipment and materials suppliers and vice versa, although each may be unprofitable at some time in the product and business cycles.
- Volume manufacturing, particularly the capability to produce high-quality and reliable components at low cost, is key in the electronics industry. It is important to stay in high-volume markets, even if they are not the most profitable, because they provide the scale and manufacturing expertise necessary to remain competitive over the long run.
- U.S. participation in large, end-product markets, such as consumer electronics, is important to provide the volume demand for components.
- High cost of capital is a barrier to success in capital-intensive industries, such as electronics.

7. Metal-Cutting and Metal-Forming Machine Tools

METAL-CUTTING AND METAL-FORMING MACHINE TOOLS	
World Market:	$38 billion (1988)[8]
U.S. Shipments:	$6.8 billion (1990)
Employment:	47,500 (1990)
Exports:	$1.9 billion (1990)
Imports:	$2.7 billion (1990)
R&D as % of Sales:	2.0% (1989)

Machine tools are a critical link in the manufacturing process. Virtually all manufacturing industries need access to state-of-the-art machine tools in order to be competitive. Machine tools are increasingly high-technology devices that depend on advanced materials and related technical fields, electronic controls and sensors, software, lasers, advanced precision bearings, mechanical design and structural dynamics.

The U.S. machine tool industry is in trouble, however. U.S. share of world production has declined from about 50 percent in 1955 to 10 percent today, and imports have taken a 50 percent share of the U.S. market.

The U.S. machine tool industry is made up mostly of small companies. These companies have not had the resources to sustain investment in technology development throughout business cycles. The industry has instead relied extensively on technology developed by suppliers and customers, and it became vulnerable to the weaknesses in these industries.

A lack of attention to manufacturing in the United States has hurt technology development in the U.S. machine tool industry. Little university teaching or research focuses on manufacturing engineering, and production engineers still have low status in most companies. U.S. manufacturers no longer lead the demand for state-of-the-art equipment. This makes it difficult for equipment manufacturers to maintain technological leadership. Conversely, a weakened machine tool industry has hurt U.S. manufacturing — when U.S. manufacturers rely on foreign machine tools, they often find that their competitors receive preferential access to the tools. This amounts to a vicious circle in U.S. manufacturing.

Machine tool industries in other countries have benefited from cooperative technology development with their customers, as well as from more supportive government policies. As a result, these industries have been able to invest in technology and enlarge their market share throughout the business cycle.

Lessons

- A vertically fragmented industrial structure has made the industry vulnerable to business cycles. The lack of cooperative customer-supplier relations in developing technology has hurt the industry.
- A high cost of capital and decelerated capital cost recovery schedules hurts U.S. capital goods producers, such as machine tool makers.
- U.S. export controls, which are enforced more strictly than those in other countries, have had a serious negative effect on the machine tool industry.
- The U.S. product liability system unnecessarily burdens U.S. manufacturing firms, including machine tool makers.
- The U.S. machine tool industry has been especially hurt by targeted foreign government policies that support foreign machine tool makers.

8. Motor Vehicles

MOTOR VEHICLES	
World Market:	$560 billion (1989)[9]
U.S. Shipments:	$215 billion (1989)
Employment:	855,000 (1990)
Exports:	$39.1 billion (1990)
Imports:	$83.3 billion (1990)
R&D as % of Sales:	3.4% (1989)

The motor vehicles and equipment industry is the largest U.S manufacturing industry. It is the largest single end-user of many materials and components and is thus a key market for many technologies.

The importance of this industry to U.S. competitiveness is graphically illustrated by its impact on the U.S. trade deficit. The trade deficit in motor vehicles and equipment represents about 40 percent of the total U.S. trade deficit. The automotive trade deficit with Japan is about half of the total automotive trade deficit.[10] This deficit has been resistant to changes in exchange rates and is forecast to continue or expand as Japanese automakers compete in more expensive cars and trucks. Imported cars and U.S.-built cars by foreign manufacturers have been capturing an increasing percentage of the U.S. automobile market. Imported cars represented 28.5 percent of the U.S. market in 1989.

U.S.-based automobile production is becoming more competitive, as U.S. automakers have rapidly improved their quality and as Japanese automakers have begun to produce in the United States. Competition has stimulated enormous improve-

ments in U.S. product and process technology. U.S.-owned automobile production remains competitive internationally, although its market share has been gradually trending down. General Motors and Ford are still the world's top two automakers, and the overseas production by U.S.-owned companies exceeds the U.S. automotive imports.

Manufacturing an automobile is a highly complex process, involving producing and assembling about 15,000 parts. As a result, a vast number of technologies and skills are critical to the industry. These include materials and electronics that are used throughout automobiles, a variety of manufacturing and process technologies and systems, and design and engineering technologies such as computer-aided engineering. Environmental technologies — such as recycling, waste management and emissions technologies — are also important. Technology comes into the industry from a variety of sources, including R&D by manufacturers, automotive parts suppliers and suppliers from other industries.

Lessons

- Many of the automobile industry's — and other manufacturing industries' — greatest competitive problems come not from weakness in hardware or computer software, but from weakness in "organizational" technologies, such as quality management and the integration of research, design and manufacturing. Internal corporate investment in, and management of, technology is key. U.S. industry often has sufficient technical resources but needs to use them more effectively.
- Solving these problems involves changing the culture of large organizations. International competition has been a critical stimulus to this change in this industry.
- In manufacturing industries, the historic lack of attention to manufacturing engineering has been harmful. Industry needs to send the right signals to encourage top people to focus on manufacturing.
- In industries that integrate components into systems, cooperative relationships with suppliers are critical to developing technologies and producing quality products. Weakness in component and equipment suppliers especially hurts the automobile industry.
- Validating the performance, quality and durability of component technologies so they can be used off the shelf has been a weak part of the commercialization process in the industry.
- Systems design and time-to-market are major weaknesses of the U.S. automobile industry.

9. TELECOMMUNICATIONS

TELECOMMUNICATIONS	
Operating Revenues	
Domestic Services:	$166 billion (1990)
International Services:	$8.0 billion (1990)
Equipment Sales:	$18.5 billion (1990)
Employment:	997,000 (1990)
Equipment Exports:	$2.1 billion (1990)
Equipment Imports:	$3.9 billion (1990)
R&D as % of Sales:	4.7% (1989)

Effective telecommunications services and equipment are vital to the efficiency of the manufacturing, services and finance sectors of the economy. Continued U.S. leadership is an important factor in the ability of these sectors to compete. Although the United States has historically had the best telecommunications infrastructure in the world, other advanced nations are modernizing their communications systems more quickly.

The telecommunications business consists of both wired and wireless communications carrier services, value-added services and associated equipment and software. The increasing convergence of computer, video and telecommunication technologies is rapidly changing the industry. Advances in network technology are distributing intelligence throughout networks; data communications are becoming possible at higher speeds; mobile telecommunications are becoming more capable; and new types of user equipment and local exchanges offer many new options.

With few exceptions, the main technical issues relate to the incremental improvement, development, manufacture and deployment of equipment using known technology.

As with other segments of the information industries, a variety of hardware and software technologies is important to the telecommunications industry. The critical technologies include user terminals, digital infrastructure, software, portable equipment and systems, optical fiber technology, broadband switching and database architecture.

Regulatory and policy decisions will be critical in determining the ability of the industry to develop and exploit these technologies.

Lessons

■ Regulatory policies, standards and judicial decisions have a significant influence on infrastructure and technology development. Federal, state and local regulatory bodies affect the desire and ability of telecommunications carriers to invest in upgrading their infrastructure. Conflicting standards and policies inhibit innovation.

■ Standards are key to allowing different parts of the telecommunications system to work together. U.S. involvement and leadership in this standards process is critical.

■ Many nations have begun to insist that patents covering official standards be licensed free of charge, which provides a disincentive for the private sector to conduct research in areas that might be covered by future standards.

■ The radio spectrum is a fixed resource. The availability of spectrum for new services depends in part on the ability to reallocate existing services.

For detailed reports on each of these nine industrial sectors, contact the Council on Competitiveness.

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[1] Data sources for statistics: Shipments and trade figures are from U.S. Department of Commerce, International Trade Administration, *U.S. Industrial Outlook — 1991*, Washington, D.C., U.S. Government Printing Office, 1990, unless otherwise noted. R&D figures are from "R&D Scorecard," *Business Week*, June 15, 1990, unless otherwise noted. All 1990 figures are estimates.

[2] Estimated free-world chemical industry shipments, Chemical Manufacturers Association.

[3] Computer Systems Policy Project, *Perspectives: Success Factors in Critical Technologies*, Washington, D.C., July 1990.

[4] Import and export figures are for Computers and Peripherals, and do not include software.

[5] For "Computers," from *Business Week*.

[6] Based on U.S. R&D statistics from Pharmaceutical Manufacturers Association ($6.6 billion) and U.S. drug shipments from the *U.S. Industrial Outlook — 1991* ($54.9 billion).

[7] For *Business Week* "Electronics" and "Semiconductor" categories.

[8] NMTBA — The Association for Manufacturing Technology, *The Economic Handbook of the Machine Tool Industry*, 1989-1990, McLean, VA, 1989, p. 163.

[9] Sum of automotive revenues of 25 largest automakers, as reported in "Business Week Global Auto Scorecard," *Business Week*, May 7, 1990, p. 54-55.

[10] Flynn, Michael S., Sean P. McAlinden, and David J. Andrea. *The U.S.-Japan Bilateral 1993 Automotive Trade Deficit*, Ann Arbor, University of Michigan Transportation Research Institute, September 1989, p. 58-59.

APPENDIX II

COMPARISON OF CRITICAL TECHNOLOGIES LISTS

The following four tables represent high-priority technologies identified by government organizations in the United States, Japan, and Europe. They include technologies from the U.S. Departments of Defense and Commerce, the Japanese Ministry of International Trade and Industry and the Commission of the European Communities.

1. U.S. DEPARTMENT OF DEFENSE CRITICAL TECHNOLOGIES PLAN

Semiconductor Materials and Microelectronic Circuits
Software Producibility
Parallel Computer Architectures
Machine Intelligence and Robotics
Simulation and Modeling
Photonics
Sensitive Radars
Passive Sensors
Signal Processing
Signature Control
Weapon System Environment
Data Fusion
Computational Fluid Dynamics
Air-Breathing Propulsion
Pulsed Power
Hypervelocity Projectiles
High Energy Density Materials
Composite Materials
Superconductivity
Biotechnology Materials and Processes

Source: U.S. Department of Defense, *Critical Technologies Plan* (for the Committee on Armed Services, United States Congress) March 15, 1990.

2. U.S. DEPARTMENT OF COMMERCE'S EMERGING TECHNOLOGIES

Materials
- Advanced Materials
- Superconductors

Electronic and Information Systems
- Advanced Semiconductor Devices
- Digital Imaging Technology
- High-Density Data Storage
- High-Performance Computing
- Optoelectronics

Manufacturing Systems
- Artificial Intelligence
- Flexible Computer Integrated Manufacturing
- Sensor Technology

Life Science Applications
- Biotechnology
- Medical Devices and Diagnostics

Source: U.S. Department of Commerce, Technology Administration, *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Spring 1990.

3. JAPANESE MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY, BASIC TECHNOLOGIES FOR INDUSTRY

New Materials
- High-Temperature Superconducting Materials
- Nonlinear Optoelectronic Materials
- Ferromagnetic Materials
- Molecular Functioning Materials
- Advanced Composite Materials
- Alloys/Metallic Compounds
- Fine Ceramics
- Carbon Materials
- Amorphous Materials
- Highly Pure Polymer Materials
- Silicon Chemical Materials
- Microelectronic Materials

Electronics
- Superconducting Devices
- Quantized Elements
- Power Electronic Elements
- Optical Elements
- Large Area Circuit Elements

Biotechnology
- Animal and Plant Cell Engineering
- High Performance Enzymes and Biomaterials
- Genetic Engineering
- Biodatabanks
- Screening and Isolation of Genes from All Sources
- Bioreactor Technology

New Material/Electronics-Related Technologies
- Atomic Level Precision Manipulation Technologies
- Metallic and Inorganic Materials Process Technologies
- Precision Molecular Alignment Technology
- Evaluation, Analysis, and Measuring Technology
- Design and Simulation Technology
- Photoreactive Process Technology
- Processing Technology for Extreme Environments

Bioelectronics
- Protein Alignment Technology
- Biomembrane Technology
- Analysis of Bio-Related Materials

Biomaterials
- Bio-Mimicing Materials
- Biocompatible Materials
- Biochemical Technology
- Bioprocessing

Computer Software and Systems Engineering
- Self-Organized Data Processing Systems
- Self-Organized Neural Networks
- Ultraparallel Processing Architecture
- Integrated Mechanical Control Software
- Software Development Technology
- Disaster Prevention Technology
- Environmental Control Technology
- Human-Related Technology
- Resource and Energy Technology
- Robotic Technology

Source: Japanese Ministry of International Trade and Industry, *Trends and Future Tasks in Industrial Technology* (Sangyo Gijutsu no Doko to Kadai), Tokyo, October 20, 1988.

4. EUROPEAN COMMUNITY CRITICAL TECHNOLOGIES

Information Technology and Telecommunications
- Electronic Components
- Software and Information Processing
- Peripherals
- Fundamental Research
- Prenormative Research (standards, systems-integration-related)
- Broadband Infrastructure
- Broadband Equipment
- Broadband Services

Industrial Materials and Technologies
- Quality and Reliability Technologies
- Techniques for Shaping, Joining and Assembly, and for Surface Treatment
- Catalysts and Membranes
- Powder Technology
- Other High-Value Materials (composites, etc.)
- Superconducting Materials

Aeronautics
- Aerodynamics and Flight Mechanics
- Materials
- Acoustics
- Computation
- Airborne Systems and Equipment
- Propulsion Integration
- Design and Manufacturing Technologies

Life Sciences
- Basic Plant Biology
- Molecular Investigation of Genomes of Complex Organisms
- Neuroscience
- Biotechnology Based Agro-Industrial Research and Technology Development

Energy
- Controlled Nuclear Fusion
- Non-Nuclear Energy
- Renewables
- Energy Efficient Technologies
- Energy from Fossil Fuels
- Energy Modeling and Environment

Source: Commission of the European Communities, *First Report on the State of Science and Technology in Europe*, Fall 1988.

About the Project

This report is the product of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy during the 1990s, 2) to highlight generic, enabling technologies that cut across sectors and boost productivity and economic growth and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology. There is no question that other issues, such as trade policy and education reform, are extraordinarily important to America's technological competitiveness. Because many other groups are already working on these issues, however, and because the Council will be focusing on them in some of its other activities, this project did not address them in detail.

Throughout the project, the Council was guided by the need to build consensus among business, labor and academia around a unified and accurate private-sector view of technology. Because the direct responsibility for developing commercial technology lies with industry, the project was rooted in an analysis of industry's needs. In order to make sure that the analysis was on target, the Council assembled an advisory committee of 30 top R&D experts from business, labor and academia (see Acknowledgments). The majority of these experts are currently involved in the development of technology. They have an intimate, up-to-date knowledge of where technology is going in their field, what competitors are doing around the world and how American industry compares.

The advisory committee oversaw the preparation of detailed reports on nine technology-intensive sectors, which represent a broad cross section of the American economy: 1) aerospace, 2) chemicals and allied products, 3) computers and software, 4) construction, 5) drugs and pharmaceuticals, 6) electronic components and equipment, 7) machine tools, 8) motor vehicles and 9) telecommunications.

The competitive profile that was developed for each of the nine sectors evaluated the sector's approach to technology, its competitive position and the key technologies driving its performance. Leading technology experts, business executives, university officials, labor leaders and representatives from industry associations all reviewed these reports to make sure that they were accurate. (A brief summary of these reports is found in Appendix I. Full copies of the industry profiles can be obtained by contacting the Council.)

Based on the information contained in these nine sectoral profiles and the deliberations of the advisory committee, the Council developed the list of generic technologies in Chapter II. Chapter III examines how governments in the United States, Japan and Europe support industry's efforts to develop technologies. The information on Japan was drawn from the Council's recent report, *Japanese Technology Policy: What's the Secret?* The information on Europe was drawn from discussions with Council members and staff research. The information on the United States was drawn from the Council's 1988 report, *Picking Up the Pace*, and the Council's extensive

experience working with key federal policymakers. In developing the recommendations in Chapter IV, the Council consulted a wide variety of public officials, policy specialists and private-sector leaders (see Acknowledgments).

The final report was approved by the Council's 25-member Executive Committee of chief executives from business, labor and academia.

From here, the Council plans to help focus national attention on these issues, to work toward implementation of the recommendations contained in the report and to explore related issues that affect America's technological competitiveness.

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This project benefited from the extensive advice and guidance of industry, academia and labor. Without the full cooperation of these groups, the Council would not have been able to develop accurate industry profiles or an in-depth policy report. In addition to many individual companies, universities and labor unions, the Council worked closely with several industry associations. The Council is especially indebted to the Aerospace Industries Association of America, the American Electronics Association, the Association for Manufacturing Technology, the Chemical Manufacturers Association, the Computer Systems Policy Project, the Motor Vehicles Manufacturers Association, the National Center for Manufacturing Sciences and the Pharmaceutical Manufacturers Association. These groups, along with many others, carefully reviewed the industry profiles and critical technologies and provided the Council with valuable information and insights.

The Council also benefited from discussions with Congressional leaders, senior staff and officials in key government agencies, including the Department of Commerce, the Department of Defense, the National Institutes of Health, the Office of Management and Budget, the Office of Technology Assessment and the Congressional Research Service. The Council was especially fortunate to be able to draw on the expertise of the White House Office of Science and Technology Policy.

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The report was edited by Kernan-Schloss Associates and designed by Carter/Cosgrove & Company.

Finally, the Council owes a particular debt of gratitude to the executives from industry, academia and labor who served on the Advisory Committee. These individuals and their organizations gave their time, energy and expertise to this effort. Over the course of two years, they actively participated in numerous policy discussions, reviewed countless drafts and scrutinized many lists of critical generic technologies. Without their contribution and guidance, this report would not have been possible. A complete list of the members of the advisory committee is provided on the following pages.

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*Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.

About The Council

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council focuses on issues in the areas of fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates — more than two dozen trade associations, professional societies and research organizations — to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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